Re-placing location: geographic perspectives in location based services

Abstract

Bringing geography closer to people's apprehension of the world has long been a goal of GIScience. Contextual and pervasive computing together with low cost technologies for positioning have provided an ideal opportunity to realise such ambitions because they allow geographic representations of the world to be brought close to individuals' engagement with it. Location based services (LBS) are an example of such a technology. They emphasise the location of a person to scope both the contents and presentation of information in ways that are contextually relevant. However, a problem exists that in the rush to tackle the complex set of technical and economic issues related to the deployment of such services, fundamental considerations about how geography should be presented and represented are often missing. Instead, more conventional spatial models for representing geographic and cartographic information have been shoe-horned to fit the purpose without a full consideration of how appropriate they may be. These tend to detach the user of the information from its material origins presenting universal, and static viewpoints in contrast to the dynamic and ego-centric perspectives innate to the mobile situations where LBS are employed. This work examines these issues through a consideration of the problem of defining ‘location'. To undertake this the traditional geographic distinctions of Space, Place, and Region are drawn on. These are treated both as concepts needing to be delineated and, perhaps more importantly, as different geographic perspectives that are employed when people conceive the world, and therefore as paradigms for informing LBS design. A central thesis posited is that at different times in the design and use of an LBS, each of these has a more or less important role in how location and locationally scoped information needs to be represented and portrayed. The research documented has been undertaken within the context of the joint European project ‘WebPark', which has developed a set of location-based services for visitors to protected and natural areas. A specific focus of the work described here has been the realisation of an application that allows visitors to access information about flora and fauna in the Swiss National Park. The description of the research proceeds by first examining, through the literature, how the triad of Space, Place and Region relate to different aspects of LBS from a theoretical basis. Based on these considerations, content analysis of a collection of visitors' questions is performed. This considers the ways in which visitors pose questions in protected areas and how these questions are related to the individual's context. These analyses are ii Abstract then synthesised to formulate a conceptual basis that informs the design of the flora and fauna service. The main body of the work is then presented. Here, the Model, View, Controller (MVC) design pattern common to software engineering is used as an explicative framework for organising the different aspects of the work. The Model section deals with how spatial and non-geographically referenced data are handled and how location can be modelled with respect to these. In particular, the perspective of Region is found to be highly pertinent for defining locations as semantically relevant geographic entities. In the Controller section the interactional facets of the service are considered, drawing on the earlier content analysis. The View section considers the importance of the situational aspects of place in portraying locations and information related to them. Here the problem dealt with is how to maintain the role of the map view as a dynamic interface for interaction and orientation under the stresses imposed by cartographic symbolisation. A set of related techniques that draw on continuous variable scale transformations are developed. These are constrained according to the structural features of the map and the intrinsic properties of the transformed map space. A number of experiments are presented that allow qualitative and quantitative comparisons to be made between the different techniques. Finally, a discussion of the application is made, drawing on the results of user testing performed in the park. Conclusions concerning the appropriateness of the techniques to the development of location based services are then provided.

Re-placing Location: Geographic Perspectives in Location Based Services

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Bringing geography closer to people's apprehension of the world has long been a goal of GIScience. Contextual and pervasive computing together with low cost technologies for positioning have provided an ideal opportunity to realise such ambitions because they allow geographic representations of the world to be brought close to individuals' engagement with it. Location based services (LBS) are an example of such a technology. They emphasise the location of a person to scope both the contents and presentation of information in ways that are contextually relevant. However, a problem exists that in the rush to tackle the complex set of technical and economic issues related to the deployment of such services, fundamental considerations about how geography should be presented and represented are often missing. Instead, more conventional spatial models for representing geographic and cartographic information have been shoe-horned to fit the purpose without a full consideration of how appropriate they may be. These tend to detach the user of the information from its material origins presenting universal, and static viewpoints in contrast to the dynamic and ego-centric perspectives innate to the mobile situations where LBS are employed.

This work examines these issues through a consideration of the problem of defining 'location'. To undertake this the traditional geographic distinctions of Space, Place, and Region are drawn on. These are treated both as concepts needing to be delineated and, perhaps more importantly, as different geographic perspectives that are employed when people conceive the world, and therefore as paradigms for informing LBS design. A central thesis posited is that at different times in the design and use of an LBS, each of these has a more or less important role in how location and locationally scoped information needs to be represented and portrayed.

The research documented has been undertaken within the context of the joint European project 'WebPark', which has developed a set of location-based services for visitors to protected and natural areas. A specific focus of the work described here has been the realisation of an application that allows visitors to access information about flora and fauna in the Swiss National Park. The description of the research proceeds by first examining, through the literature, how the triad of Space, Place and Region relate to different aspects of LBS from a theoretical basis. Based on these considerations, content analysis of a collection of visitors' questions is performed. This considers the ways in which visitors pose questions in protected areas and how these questions are related to the individual's context. These analyses are then synthesised to formulate a conceptual basis that informs the design of the flora and fauna service. The main body of the work is then presented. Here, the *Model*, *View*, *Controller* (MVC) design pattern common to software engineering is used as an explicative framework for organising the different aspects of the work. The *Model* section deals with how spatial and non-geographically referenced data are handled and how location can be modelled with respect to these. In particular, the perspective of Region is found to be highly pertinent for defining locations as semantically relevant geographic entities. In the *Controller* section the interactional facets of the service are considered, drawing on the earlier content analysis. The *View* section considers the importance of the situational aspects of place in portraying locations and information related to them. Here the problem dealt with is how to maintain the role of the map view as a dynamic interface for interaction and orientation under the stresses imposed by cartographic symbolisation. A set of related techniques that draw on continuous variable scale transformations are developed. These are constrained according to the structural features of the map and the intrinsic properties of the transformed map space. A number of experiments are presented that allow qualitative and quantitative comparisons to be made between the different techniques. Finally, a discussion of the application is made, drawing on the results of user testing performed in the park. Conclusions concerning the appropriateness of the techniques to the development of location based services are then provided.

Zusammenfassung

In der Geographischen Informationswissenschaft gibt es schon länger Bestrebungen die Warhnehmung der Welt durch die Menschen besser mit der geographischen Repräsentation zusammenzubringen. Contextbezogene und pervasive Computersysteme zusammen mit der Verfügbarkeit von billigen Positionierungstechnologien eröffnen nun Möglichkeiten, die geographische Darstellung der Welt nahe zu den Menschen und deren Tätigkeiten zu bringen. Location Based Services (LBS), als ortsbezogene Dienste, sind ein Beispiel für eine derartige Technologie. In ihnen beeinflusst der aktuelle Aufenthaltsort einer Person den Fokus und die Darstellung von Informationen, so dass sie für den spezifischen Kontext relevanter sind. Allerdings werden beim Bewältigen der technologischen und ökonomischen Implikationen dieser Technologien oft fundamentale Fragen über die geographische Modellierung und Darstellung vernachlässigt. Ohne Betrachtung der Eignung wurden konventionelle räumliche Modelle für die Repräsentation geographischer und kartographischer Informationen angewendet. Diese Modelle zeigen allgemeine und statische Blickwinkel anstatt dem mobilen Benutzer während er LBS benutzt die Information in einer dynamischen benutzerzentrierten Perspektive anzubieten.

Diese Arbeit untersucht diese Fragen indem es das Problem der Definition des 'Standortes' (engl. *location*) berücksichtigt. Dazu wird die traditionelle geographische Unterscheidung der Konzepte von Raum (*Space*), Ort (*Place*) und Region (*Region*) herangezogen. Diese werden sowohl als zu beschreibende Konzepte und, vermutlich wichtiger, als unterschiedliche geographische Perspektiven bei der Wahrnehmung der Welt behandelt. Daher können sie als Paradigmen für das Design von LBS dienen. Eine zentrale These der Arbeit ist, dass jedes dieser Konzepte zu unterschiedlichen Zeiten bei Entwurf und Benutzung von LBS eine wichtige Rolle bezüglich der Darstellung der aktuellen Position und der ortsbezogenen Informationen spielt.

Die beschriebene Arbeit wurde im Rahmen des europäischen Projektes 'WebPark', in dem Location Based Services für Besucher von Naturparks und Naturschutzgebieten entwickelt wurden, durchgeführt. Spezieller Fokus dieser Arbeit war die Entwicklung einer mobilen Anwendung, die es Besuchern des Schweizerischen Nationalparks erlaubt, Informationen über Flora und Fauna abzufragen. Die Beschreibung der Forschung untersucht zuerst, anhand der Literatur, wie die Dreiergruppe aus Raum, Ort und Region mit den verschiedenen Aspekten von LBS auf theoretischer Ebene zusammenhängen. Aufbauend auf diesen Überlegungen wird eine Analyse einer Sammlung von Fragen von Nationalpark-Besuchern durchgeführt.

Dies bezieht sich auch auf die Art und Weise wie Besucher von Schutzgebieten Fragen stellen und inwiefern diese Fragen mit dem Kontext des Besuchers zusammenhängen.

Diese Analysen dienen dann als konzeptuelle Basis für das Design des Flora- und Fauna-Dienstes. Danach wird der Hauptteil der Arbeit präsentiert. Das *Model*, *View*, *Controller* (MVC) Design-Pattern aus der Informatik dient als Rahmen, um die verschiedenen Aspekte der Arbeit zu strukturieren. Das Kapitel *Model* zeigt, wie räumlich sowie nicht-räumlich referenzierte Daten behandelt werden und wie der Raumbezug mit diesen modelliert werden kann. Insbesondere der Begriff der Region eignet sich für die Definition von Orten als semantisch relevante geographische Einheiten. Im Abschnitt *Controller* werden die Askpekte der Benutzerinteraktion betrachtet, ausgehend von den Analysen der Benutzerfragen. Der Abschnitt *View* diskutiert die Wichtigkeit von situationsbezogenen Aspekten von Orten (Place) beim Anzeigen von Standorten und relevanten Informationen. Hierbei wird das Problem der Realisierung dynamischer Kartendarstellung und Interaktion zusammen mit kartographischer Symbolisierung behandelt. Dazu wurden Techniken, basierend auf kontinuierlicher variabler Massstabstransformation, entwickelt. Diese werden durch die strukturellen Objekte in der Karte und durch die inhärenten Eigenschaften des Kartenraumes beschränkt. Mehrere Experimente zeigen quantitative und qualitative Vergleiche zwischen den verschiedenen Techniken. Schlussendlich wird die Anwendung und die Resultate der Benutzertests im Nationalpark diskutiert. Schlussfolgerungen bezüglich der Eignung der Techniken für die Entwicklung von Location Based Services werden gegeben.

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Contents

Chapter 1

Introduction

1.1 Motivation

One of the most captivating aspects to studying Geography is that it appeals to the external for its substance: the structures and processes that construct the world and peoples' individual and communal conceptions of their surroundings. A lament for many researchers in Geographical Information Science (GIScience) is the distance between them and this experience, created by replacing the complexities of the world with digital representations and abstractions that encode it.

It is unsurprising then that the idea of Location-based Services (LBS) should be so alluring. It offers an opportunity to re-situate the study and practise of GIScience back into the "real-world" and in people's innate geographic experiences of this. At the same time, they retain the enchantment of the methods that have been forged in GIScience, placing side-by-side the phenomenon and our knowledge about them (Armstrong and Bennett, 2005).

However, this happy mix is far from being without its problems. GIScience has to a large degree operated on a plane that is objective, universal, static and abstract. This detachment is necessary to study spatial phenomena analytically. However, with location-based services it becomes less tenable. As services, LBS aim to provide information through momentary and ephemeral transactions and in ways that are highly influenced by the individual user of the service. LBS' subject matter is therefore people and their direct engagement with the world in space and time (Raubal et al., 2004). This is a fundamentally subjective, or "ego-centric" (Meng, 2005) standpoint. People's geographical mindset changes when their experience of the space is developed from this immersed perspective. It is very different from the detached view of space employed for capturing, representing and analysing geographic data.

This suggests a theoretical gap in how geography can best be presented and represented in LBS. A number of researchers have approached this problem by focusing particularly on the user and their spatio-temporal behaviour (Mountain, 2006; Raubal et al., 2004), activities (Kuhn, 2001), and contexts (Nivala and Sarjakoski, 2003). These considerations have then been applied to how maps for LBS are designed (Meng and Reichenbacher, 2005).

Aspects of these issues are also considered in this work. However, here the principal focus is on geography as the context of location. This is why the, perhaps outdated, term of 'location-based service' is used rather than one of the many others, for example; "map-based mobile services" (Meng, 2005; Meng and Reichenbacher, 2005), "mobile information services" (den Hengst et al., 2004), or "context-aware computing" (Schilit et al., 1994).

Location is an appropriately ambiguous term (Schlieder et al., 2001). It refers not only to the continuously changing position of a user, but also their relation to the places, things and people that interweave across space, time and scale in the course of interacting with the world. As such, location can not easily be separated from the context in which it is made meaningful. Location can be modelled in different ways. In the Computing literature, these are often categorised as geometric, symbolic and semantic (Hu and Lee, 2004; Hsieh and Yuan, 2003). Geometric locations are distance neighbourhoods around a user's location, where the distance might be measured in different ways, e.g. radially or through a network and the location might be represented as a position or a path. Symbolic locations are essentially addresses, often defined hierarchically. Examples are the location of a person within a building; e.g which floor and which room they are in on that floor, and postal zones. Semantic locations use the semantic meaning of a zone that a person is in to define a context to their actions. For example if someone has stopped by a bus-stop they are probably interested in taking a bus. Semantic locations can also be defined by social relations e.g. the people who you are near. In this sense a location might be 'With Bob'. Figure 1.1 illustrates different schemes.

What this classification obscures is there are fundamental differences in what location means and how it can be employed. These are determined not by variations in the way location is represented, but rather by differences in how location is understood geographically. Location as a 'thing', geometrically bounded, is a very different concept to location as a milieu created ephemerally through social interaction or to location as a setting for the performance of different types of activities. At different times any one of these may the most appropriate to the user of an LBS hence in designing an application it becomes critical to attempt to consider what location means to the user and how it might be presented.

1.2 Research Objectives

The purpose of this work is to investigate how different perspectives in geographic thinking need to be accounted for in the design of LBS. This is explored through the triad of *Space*, *Place* and *Region*, both as geographic instances but, more importantly, ways of understanding and describing the world. Simplistically, space is understood to mean the form of thinking that allows us to make quantitative statements involving the world, e.g. "How big is ...?" or "How far is ...?". Regions

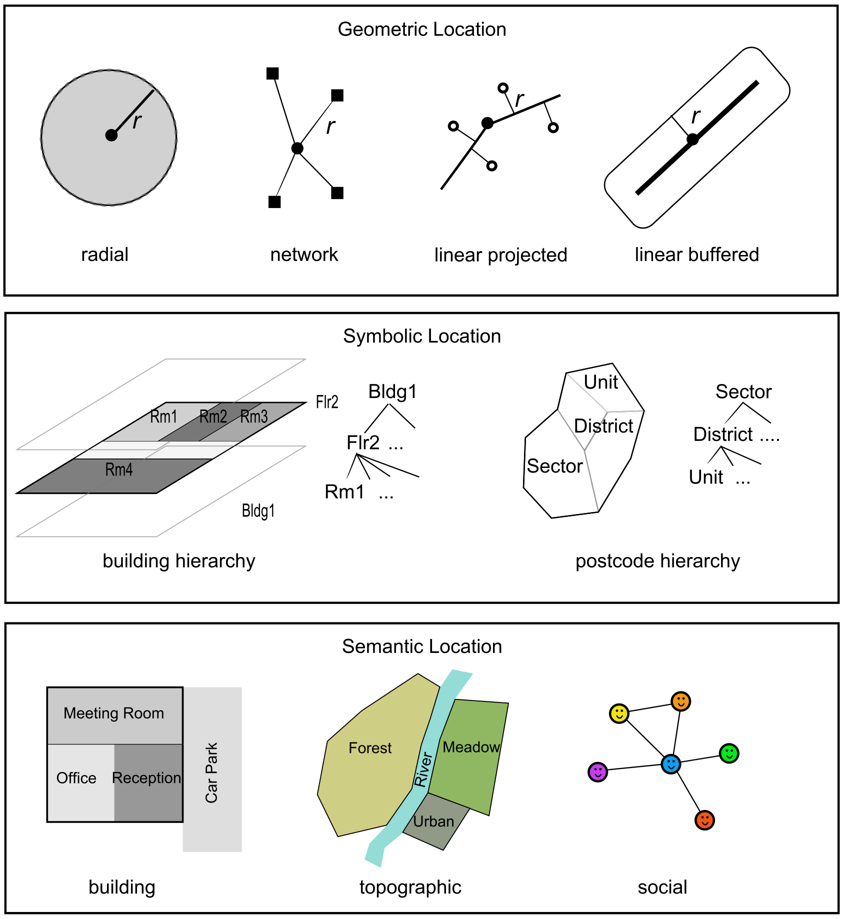


Figure 1.1: Different models for location

allow the world to be conceived qualitatively, consisting of categories related to cognition and language (Montello, 2003). Thus, differences and similarities among areas can be described e.g. habitats and cultural districts, and their properties questioned "What is this like?". Places are created as centres for actions, meanings, interactions and everyday rituals. They relate to human experience and perception. "What is this?", "Where can we meet?", "How can I get to?". This triad then provides a conceptual basis for handling and presenting geographic information in support of people and their activities, cognition and interactions. Based on these considerations, the main aim of the research is then to instantiate these ideas within a working location based service for providing information about flora and fauna to visitors of a protected area.

The central thesis of the work is that these different ways of thinking about geography need to influence the representation and presentation of information and location in LBS. This argument is investigated through aspects of analysis, design and implementation of an LBS for visitors to natural and protected areas. Such environments are relatively under-researched in LBS, with most examples focusing on the activities undertaken in urban environments, on road networks, or within buildings. The setting finds a set of unique characteristics that relate to the types of activities performed in protected areas and interests of people when visiting them. To cope with these a broader range of geographical standpoints must be employed than would be encountered in a more structured environment, providing particular challenges to representing and presenting geographic information. In addition, it builds clear further motivation for the work, to support custodians in achieving their conservation aims, in particular by informing and educating visitors through the deployment of knowledge within an LBS.

1.3 Research Questions

1. "What are the essential characteristics of Space, Place and Region that should be employed in the analysis and design of location based services?"
    - "How can these be effectively identified in an analysis process?"
    - "How can they inform the different elements of LBS design?"
2. "To what extent can the spatial modelling of information and location be influenced by the perspectives of space, place and region?"
    - "What qualities can be used to represent locations and should these relate to the information they need to index?"
    - "How can users supported in creating places through their activities?"
    - "How important are spatial representations of information, such as distributions, to users of an LBS? Are there methods for portrayal that users prefer?"
3. "In what ways are maps and map interfaces for location based services distinct from those of more conventional forms of mapping such as paper and web maps and how can these considerations be implemented in dynamic solutions?"
    - "Can a transformational approach to map adaption be employed to manage such properties?"
    - "What are the situational aspects of location and graphical constraints that need to be mediated for in such solutions?"

1.4 Outline of the Thesis

This work does not aspire to generate nomothetic or prescriptive solutions, but rather takes a practical viewpoint to explore the issue of representing geography in

LBS. It consists of four thematic parts comprising a number of chapters. The first theme develops the basis for the research from a theoretical standpoint. Informed by this theory, the second analyses the needs and uses of an LBS in the context of an application to support a visitor's activities related to discovering wildlife in a natural or protected area. The third theme describes the design and implementation of this analysis within the architecture of an LBS. In the final theme, the testing of the system is described and a discussion made of the approaches used.

1.4.1 Theoretical Foundations

In Chapter 2 the theoretical background to this work is described. This draws on thinking from Geography in the main as well as reviewing relevant literature from related technological fields such as LBS, Computer Cartography, Ubiquitous Computing and Human and Computer Interaction (HCI).

1.4.2 Research Context

In Chapter 3, the specific context of this work is described. This is the European Commission funded IST project WebPark (WebPark, 2001). The objectives, structure and situations of this project are described together with the position of this research within it. In addition, a review is made of the needs for applications and information gathered from visitor consultation and observation.

1.4.3 Analysis

In Chapter 4, a detailed investigation is made of how user activities, interaction and needs for information are expressed within a natural and protected area. This draws on primary data from questions about wildlife that visitors asked personnel whilst engaged in activities in the Swiss National Park (SNP). It employs qualitative techniques to code and analyse this documentary data.

1.4.4 Design and Implementation

In Chapter 5, the design of an architecture for LBS is presented based on the decomposition of the Model-View-Controller design pattern (Gamma et al., 1995). This sees systems for LBS as comprising of a data component, an interaction (interface) component, and a portrayal component. Each relates to particular aspects of LBS: the representation of geographic information and location, the structuring of actions and exploration of information, and the presentation of information with respect to an activity.

In Chapter 6, the information model is described. This comprises two interrelated parts; the information model and the location model. The chapter first describes issues in gathering and evaluating of existing spatial data resources for use in an LBS. It then details how information was prepared and structured. The topic of developing a model for location is then discussed in light of the previous theory and analysis. Its implementation is expounded and how this was related to the information model is then described.

In Chapter 7 the LBS is described from an interaction perspective. This develops the dynamic aspects of the system in relation to the activities identified in Chapter 4. It explains the various interfaces and use-cases used to provide control over the system.

Chapters 8 and 9 deals with issue of dynamic portrayal of geographic information in location based services. This describes the role of the map as a view, incorporating aspects of user interaction and context with considerations for effective graphical display. In particular, these sections present concepts and algorithms that employ transformational approaches (Tobler, 1973) to the problem of reorganising volatile map features. In Chapter 8 a set of different techniques is proposed and their relationship to other techniques for portrayal outlined. Chapter 9, then presents a set of quantitative and qualitative experiments aimed at comparing the results of the different solutions.

1.4.5 Discussion and Conclusions

Chapter 10 discusses the issues explored in relation to the theory presented in Chapter 2 and in light of user testing carried out at the end of the WebPark project. It reviews the strengths and weaknesses of the approaches in relation to the research questions posed above, and identifies the lessons learnt.

In Chapter 11, conclusions are drawn on the work and the important contributions are highlight. An outlook for future work is then presented.

Chapter 2

Mobile Geographies

2.1 Introduction

Location-based services present an ambitious proposition for a number of reasons. For a start, they try to address a complex set of technical (Adams et al., 2003; D'Roza and Bilchev, 2003), infrastructural (Smith et al., 2004), and privacy (Fisher and Dobson, 2003; Dobson and Fisher, 2003) challenges needed to balance a delicate chain of technologies and information service providers, the so-called 'value chain' (Barnes, 2003). Arising out of these are then a plethora of potential applications, each of which has particular peculiarities in terms of its markets and consumers (Shiode et al., 2004; Spiekermann, 2004).

Addressing these sorts of issues has dominated much of the LBS research and development agenda. To do so, LBS have needed to inherit and exploit the methods of related and more mature geo-spatial technologies, without a thorough consideration of the suitability of these to the particularities of LBS. This has meant that LBS have been stifled in developing their own body of methods and theory (Meng, 2003), too often being seen as a 'mini-GIS'.

LBS also seek to situate their use in a position of everyday life that is unique within complex information services (Sui, 2004). They aim to mediate in peoples' direct, dynamic, and transient experiences of the world. This creates exceptional issues in how geographic information is presented and made accessible. Underpinning these issues are fundamental questions about the nature of geographical experience of LBS users.

The aim of this chapter is to investigate, via the literature, how LBS as, personal, mobile, service-oriented and contextual technologies, are influenced by the ways geographic knowledge is created, represented, used, and communicated. This will provide a theoretical underpinning for later analysis and discussions.

To examine these issues the chapter explores how different perspectives in Geography might relate to LBS, how these have been employed in current LBS research, and what problems emerge from these considerations.

2.2 Geographical Perspectives in LBS

A conventional view is that geography is the study of *space* and *place* (Fisher and Unwin, 2005). These seemingly simple categories underlie many of the differences among geographers both in terms of what they study and how they go about it. As pointed out by Curry (2002):

> "It may at first glance seem that the matter [of space and place] is simple - the world is a world of places within a larger space. . . . When one turns to concrete questions, about the source of territorial disputes, and the possibility of their resolution; or about the extent of and connections among markets; or about the appropriate ways to draw a map of the world, one immediately finds sets of beliefs so contradictory and yet so firmly held that this simple 'location in space' understanding of places emerges as quite useless. Something better is needed." (p.502)

2.2.1 The Space–Place Continuum

The concepts of place and space are often examined in respect to a continuum of geographic viewpoints that range from the particular and the experiential to the abstract and the universal (Entrikin, 1997; Couclelis, 1992). Place is most distinct at the start, relating geography to human existence, experiences and interaction (Relph, 1976). At the other end is a more detached, abstract and objective and view of space, for example as geometry (Gieryn, 2000), which provides the means to think about and describe the world in a logical way. Figure 2.1 illustrates the continuum.

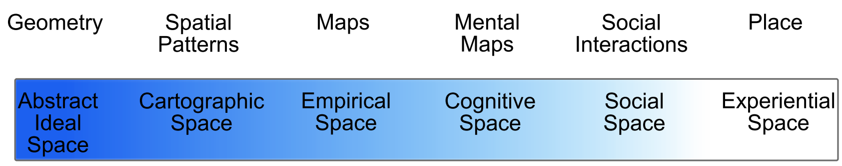


Figure 2.1: The space–place continuum

Reconciling the two ends of this continuum has proved difficult (Entrikin, 1991; Merrifield, 1991) and thus space and place have in general been approached from different sections of the geographic domain. Place has taken a more fundamental role in humanistic geographic traditions (e.g. Cresswell, 2004), whereas, (objective-) space has been dominant particularly in GIS and spatial analysis (Goodchild, 1992; Raper, 1999; Miller and Wentz, 2003). As Fisher and Unwin (2005, p. 6) comments

> "GI theory articulates the idea of absolute Euclidean spaces quite well, but the socially-produced and continuously changing notion of place has

> to date proved elusive to digital description except, perhaps, through photography and film."

.

The significance of these attitudes to location-based services arises because they need to mix different geographic perspectives in presenting useful services and information. This is highlighted by Longley (2004) who notes, "The historical demarcation in psychological and behavioural geography between direct and indirect experience blurs when handheld devices are used as an adjunct to reality in the field."(p.114).

Whilst the same might be said of a person using a paper map or GIS in the field, there are differences. LBS are services, and paper maps and GIS products. In economics terms, services can be differentiated from products by four aspects characteristics, using the so-called SHIP acronym (den Hengst et al., 2004).

- Simultaneously produced and consumed
- Heterogeneous: the service is unique for each use, interaction and situation
- Intangible
- Perishable: the act of consumption removes their value.

SHIP describes a pure service and as such is quite broad, for example it could refer to a hair-cut. For many services including LBS, the distinction is not so clear-cut. An LBS presents information and requires hardware to run on and is therefore not completely intangible. The information produced by a transaction may have currency for a period of time and so is not strictly simultaneously produced and consumed. However, the service characteristics result in the nature of LBS as creating outputs that are ephemeral and determined uniquely for a single individual, situation, purpose and transaction. This differs from a map or GIS product which is created as something lasting and generic.

LBS therefore seek a far more intense and intimate relationship with the consumer, their interests, intentions and actions. This forces a focus much more on the subjective experience of the user in space, often referred to as *ego-centric* design (Meng, 2005). To achieve this LBS must strive to allow its users to *create places*. At the same time, LBS adopt the objective framework of a cartographic product to present the context of activities and as a method of organisation for describing and reasoning about geo-spatial phenomena. In doing so, LBS draws on spatial tools and models essentially *creates spaces*. And so, the dichotomy between place and space emerges.

2.2.2 Place

Place has been described as a *contested* concept (Agarwal, 2004; Cresswell, 2004), defying any universal definition and often being described in reference to other spatial terms such as neighbourhood, region, and location. A number of authors have sought to identify the essential and inter-related components of place. For Relph (1976), in geography, place, or the identity of a place, consists of the physical setting, the activities that are performed there, and the meanings it is endowed with. From a psychology perspective, Canter (1997) identifies *facets* of place as, functional differentiation (activities), place objectives, scale of interaction, and aspects of design (physical setting). Gustafson (2001) posits a triad of the self, others and the environment, to classify meanings people attach to place. From a social science perspective, Gieryn (2000) highlights geographic location, material form and investment in meaning. Similarly, Agnew (1987) identifies locale (setting), location, and sense of place. In each of these there is an overall emphasis on place as the confluence of physical and human factors coming together when space is experienced and made meaningful through activity and interaction. What is important to consider in LBS is if these factors can be represented either explicitly as geographic features or implicitly by supporting the types of activities and reasoning that allow people to differentiate space (Tuan, 1977).

Place as a Thing

The quintessential representation for places is by a name. When places are identified they become to some extent objective features of a landscape. For example as denominated morphological features (Fisher et al., 2004) or as settlements. This latter form is most keenly recognised in a gazetteer. Hill (2000) describes gazetteers as "geospatial dictionaries of geographic names" (p. 280). She list three components to an entry in such a dictionary:

- a name - identity, can have multiple entries e.g. international name, name in home languages etc.
- a location - a geo-spatial *footprint* e.g. point, line or area.
- a type - semantics defined by a categorisation scheme for places.

  (Hill, 2000, p. 280)

Hill discusses the difficulties in geo-referencing places. She suggests five types of representation that might be used, point, bounding box, line, polygon, and grid representation, but notes that ultimately places are inherently imprecise being scale dependent and subjective. She suggests the criterion of *satisficing* should be applied to the selection of a footprint. That is to take the solution that is satisfactory given the cost and the diminishing returns provided by greater accuracy.

A number of researchers have considered the issue of representing footprints for the purpose of information retrieval based on place names. Schlieder (1996) describe how polygonal subdivisions, e.g. districts, can be represented qualitatively using connection graphs in order to support spatial queries. Jones et al. (2001) discusses the issue in relation to determining metrics for relevance ranking that consider both geographical as well as semantic closeness. Jones et al. (2004) discuss the creation of a geo-ontology based on geographical place names and its use in a spatio-textual index, in the context of the project SPIRIT. Agarwal (2004) has attempted to clarify the concept of place, seeking to distinguish the semantic similarities between place and other related spatial concepts (region, neighbourhood, location, space, time, district and area). Her work involved asking test subjects to make similarity judgements about the various notions. In her analysis, she found that locations, neighbourhoods and districts are largely conceived as examples of a type of place, whereas space, area and region are understood as higher-order concepts. In particular, she found a close relationship between place and region allowing her to infer that region is a super-type for place.

An issue with this work is that it assumes place must be something ontological, essentially a semantic construct for cognition. From this starting point, it is perhaps inevitable that place becomes bound up with the notion of region. However, place can also be understood not as a concept of a mental schema or as a spatial object but rather, epistemologically, as an approach to creating knowledge. As Cresswell (2004) comments "place is not just a thing in the world but a way of understanding" (p.11).

Place: The Experiential Perspective

Some of the most influential work on place as *a way of understanding*, rather than a thing, has been that of the phenomenological geographers. This view sees geographical knowledge founded on by the experiences and consciousness people have of the world (Relph, 1976, p.4).

Relph (1976) characterises space as an "amorphous and intangible" entity that can not be directly described and analysed (p.8). Place comes about as a way of making sense of it. This view is echoed by Tuan (1977) who explains; "What begins as undifferentiated space becomes place as we get to know it better and endow it with value." (p.6). Relph, however, advocates that a knowledge of place precedes the construction of more formal spatial notions such as locations, regions and landforms. It relates the initial and immediate experience of the world that allows geographic reality to be fixed in memory through centres of meaning.

Both these authors recognise a range of forms of space relating to different types of geographic experience. These experiences can be both "direct and intimate" or "indirect and conceptual, mediated by symbols." (Tuan, 1977, p.7). Relph describes a continuum consisting of six different kinds of space:

- pragmatic or primitive – which relates to the instinctive and unselfconscious space people act in without reflection,

- perceptual – comprising space experienced consciously and egocentrically through movement, sight and touch, as well as emotion,

- existential – consisting the space of living, structured by shared cultural meanings and names,

- architectural and planning – space consciously created for specific functions and interactions rather than emerging through human experience,
- cognitive – the objective space of theorisation, such as described through geometry and maps, and
- abstract – space that is created by the imagination, with no empirical basis, it consists only of symbols and abstract relations.

  (Relph, 1976, Ch.2).

Likewise, Tuan (1977, p.152) states;

> "To know a place fully means both to understand it in an abstract way and to know it as one person knows another. At a high theoretical level, places are points in a spatial system. At the opposite extreme, they are strong visceral feelings. Places are seldom known at either extreme; the one is too remote from sensory experience to be real, and the other presupposes rootedness in a locality and an emotional commitment to it that are increasingly rare."

The phenomenological approach is concerned largely with the former half of this continuum: the primitive, perceptual and existential spaces. In particular, how places are recognised and identified from these perspectives. Relph (p. 47) proposes three fundamental elements that constitute the identities of places; Their static physical setting, the activities engaged within this setting, and the meanings attached to it.

Place in Technology Design

The intuitions of the phenomenologists have been influential on a number of researchers who have sought to capture the notion of place and sense of place in the geographical representations of computer systems. One of the most common example is by that more closely relate to the perceptual experience of moving through space, for example in 3D virtual environments. However often here the emphasis is on the spatial reference of the user rather than on how they encountered places. Turner and Turner (2006) have discussed the need to augment photo-realistic virtual environments with a sense of place in order to *re-create* the feeling of being in the actual places. Their analysis identified dimensions of, physical attributes, activities, meanings and affect, and social interaction, as significant aspects in how people experience place.

Similar observations have been made by Harrison and Dourish (1996), who have argued that in the field of Computer Supported Collaborative Work (CSCW) there is a misplaced emphasis on spatial models to suggest frames of appropriate behaviour in particular circumstances. Instead, they advocate that appropriate behaviour emerges from a sense of place rather than space, and hence an understanding of place needs to be built into design. The same argument might be directed to LBS and its emphasis on the spatial, inherent by the word 'location', when what many services are actually considering is place. This is clear from the language of services such as *city* guides, *landmark*-based navigation (Hampe and Elias, 2003; Gartner, 2004) or *point-of-interest* searching.

Harrison and Dourish (1996) see something that place (or sense of place) needs to be an emergent property of technologies and suggest *hybrid spaces*(p.6) as a method for achieving this. Chalmers (2001) also take up these observations in relation to systems that "deliberately blurs the boundaries between physical and digital spaces" (Chalmers, 2001, p.38). They applied these ideas to the design of such a system, a mobile information resource for the city of Glasgow, which combined mobile computers, hypermedia and virtual environments. The system attempted to develop a resource by initially focusing on the historical figure of Charles Rennie Mackintosh and extending from aspects of his life a range of different places. Ciolfi and Bannon (2005) also use the notion of place to explore the design of hybrid spaces. They designed an interactive museum exhibition space that co-exists with the real galleries of the Hunt Museum in Limerick. By studying how the real museum is experienced as a place by visitors, curators and other staff, they could introduce these experiences into virtual exhibition spaces that could be explored through touch, seeing and hearing.

Other work has looked to enhance the sense of place by focusing on how spaces are perceptually encountered. Llobera (2005) discusses this with the goal of developing a phenomenological perspective in GIS. He focuses on the role of visual perception in structuring space and spatial experience, developing the concept of a *visualscape* (Llobera, 2003) to explore the perception of terrain. This echoes Tuan (1977, p.17) who notes "Systems of geometry–that is, highly abstract spaces–have been created out of primal spatial experiences." Bartie and Mackaness (2006) likewise draw on the role of perceptual experience to organise information about features of interest within the city of Edinburgh. They describe a system that pre-calculates visibility for various interesting buildings taking into account their shape and how they are shadowed from sight by other structures. They use this model to present information to mobile visitors via automated speech through a wireless device. Such a model emphasises the broad experiential potential of location-based services, as Sui (2004) notes: "Different from all the previous media, LBS is in principle capable of integrating all the three major modes of human communication: oral, textual, and electronic." (p. 64).

Activity and Action

Whilst LBS do not necessarily seek to re-create places virtually, they often desire to mediate in the activities of everyday life that depend on or create places during their execution.

The belief that activities and action play a fundamental role in shaping people's experience and understanding of space and place has long held currency in human geography (c.f Thrift, 1996). More recently, such ideas have been vocalised by researchers in LBS and GIS. Miller (2003) has presented a case for re-focusing geographic models on the activities and interactions of individuals rather than aggregate patterns of socio-spatial behaviour tied to geographic locations. He extends Hägerstrand's time-geography as a mechanism for achieving this. In related work, Mountain (2006) and Mountain et al. (2003) investigated how a knowledge of people's spatio-temporal behaviour, described through their everyday *mobile trajectories*, can indicate the places that are meaningful in their lives and provide a basis for evaluating the *geographic relevance* of information for different people in LBS. Similarly, Schlieder et al. (2001) have suggested that patterns of motion can be used to disambiguate context among the various scale-dependent places and regions that are relevant to the activities and interactions of people at a particular time.

Activity Theory

In cartography, a number of researchers have explored how activity should be integrated into the design of maps for LBS. Dransch (2005) has drawn on Activity Theory from HCI (Nardi, 1996a). Here activities are structured using a hierarchy of plans, goals, sub-goals and actions. Within this paradigm maps are described as artifacts. They are tools used to execute the activity and are in mutual relation; the artifact being defined for the purpose of the activity and the the activity being structured by the artifact. Reichenbacher (2004) was similarly influenced by activity theory. He bound it to the ideas of context (discussed later in Section 2.2.2) to illustrate how mobile maps could be *adapted* (Zipf, 2002) according to the nature of a situation.

Situated Action

Brown and Laurier (2005a,b) also considered the role of activity in map design, but took the perspective of *situated action*. This differs from activity theory in that it rejects the idea that persistent constructs, such a goals and plans, shape activity. Instead, it focuses on how the situation suggests the actions that should be performed and thus activity is essentially improvised: "the organization of situated action is an emergent property of moment-by-moment interactions between actors, and between actors and the environments of their action." (Suchman, 1987, cited in Nardi, 1996c). Brown and Laurier also saw (electronic) maps as artifacts, but investigated their role as media for collaboration among small groups of people sharing activities, using ethnographic methods such as direct observation.

The two models for interaction suggest two types of place in LBS. One is created by the user through their own improvised actions and interactions. Services can support these by being open to exploration and serendipity. In the other, places are representational. They structure pre-defined activities or actions and allow people to add meaning to them through their own experiences.

Centres of Meaning

Places develop for people as they invest meaning and value in them. This might be through naming places, identifying with them and representing them (Gieryn, 2000). LBS can help people to attach meaning in a number of ways: by attaching value, by allowing people to create and recall places, and by enabling people to develop a shared experience of place within a community.

LBS can attach value by adding historical, cultural, social and environmental settings, for instance, through multimedia, historical documents and narratives. This is the core aim of many LBS tourist applications and city guides (e.g. Abowd et al., 1997; Cheverst et al., 2000; Poslad et al., 2001). For example, the GUIDE project (Cheverst et al., 1999, 2000) used a model of interconnected 'location objects', such as galleries and castles, to which multimedia information about the location is associated. Thus their perspective was fundamentally place-based. In fact, whilst they used the term 'location', their model did not require any spatial representation. Places were organised instead using a graph with way-finding instructions describing how to navigate links. This emphasises an important aspect of place, that it does not require space, at least as described geometrically, for its definition.

Social interaction can also give meaning to places by allowing them to create and share places. This is important for services that support locating friends (Strassman and Collier, 2004), and 'social navigation' (Höök et al., 2003). Examples of the latter are the GeoNotes (Fagerberg et al., 2003; Espinoza et al., 2001) and E-Graffiti (Burrell and Gay, 2002) systems. These allow people to post virtual notes or tags in locations that can be accessed and exchanged by friends and peers as they move through locations. Hence ephemeral places are created based on interactions such as meeting-points or communal events.

Place and Context in LBS

Location is one aspect from a number of situational variables that have a bearing on how information services can be made relevant to their context of use. The inspiration of systems that are context-aware was first developed in the field of ubiquitous computing (Weiser, 1991). Various researchers have sought to define and classify context and context-aware computing within this field. On the one hand, definitions sought to itemise different aspects that come together as context. Schilit and Theimer (1994) identify the components of: location, identities of nearby people and objects and changes to those objects.

Nivala and Sarjakoski (2003) have applied these considerations to the design of maps in LBS. They present five general types of context each of which can be sub-categorised further. These consist:

- Computing - The type of device being used and its characteristics (input modalities, screen, connectivity etc.)

- User - The identity of the user, their personal preferences and relationships with other users

- Physical - The environment the service is being used in, the location of the user, the direction they are travelling
- Time - When the service is being used according to different time scales (e.g. time of day or season of the year)
- History - The history of the user's navigation both spatially and in terms of the information they have looked at

Dey (2001), reflects on a number of previous characterisations to formulate a more general definition

> "Context is any information that can be used to characterise the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." (p.3)

They highlight the elements of location, (user) identity, activity, and time as being the most important in practical terms.

Dourish (2004) criticises these reductionist approaches to context, arguing that they define the problem as one of representation and assume context is; a form of information, delineable, stable, and separable from activity (pp.21–22). He instead presents a phenomenological account that emphasises context as an interactional problem. From this perspective he argues that context can not be unbound from the activity. Context comes about because of the activity.

Such discussions suggest the notion of place shares many of the characteristics of context. Whilst location of a user is a variable continuously changing in space, how activities are situated coincides with, or involves the creation of, places. Place therefore becomes the setting for activities and a frame for appropriate behaviour (Harrison and Dourish, 1996). How places are experienced will in turn be shaped by both individual values and shared meanings developed through communal interaction.

Affordances

The view that place is a context simultaneously defining and defined by the actions and activities of people is inherent in the Gibsonian theory of affordances (Gibson, 1979). The term affordance refers to the possibilities for action that an environment provides.

> "The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal

> in a way that no existing term does. It implies the complementarity of the animal and the environment." (p. 127)

Gibson considers the nature of places within this theory in saying:

> "The habitat of a given animal contains places. A place is not an object with definite boundaries but a region.... The different places of a habitat may have different affordances. Some are places where food is usually found and others where it is not. There are places of danger, such as the brink of a cliff and the regions where predators lurk. There are places of refuge from predators. Among these is the place where mate and young are, the home, which is usually a partial enclosure. Animals are skilled at what the psychologist calls place-learning. They can find their way to significant places." (p. 136)

A number of researchers have drawn on this theory to develop models for GIS and LBS. Jordan et al. (1998) have presented a methodology for integrating the concept of place in GIsystems using affordances. They consider three aspects of affordances: the agent (user's capabilities), the environment and the task requirements. They describe how these can be used to support representation in a GIS of the different aspects of place: physical features, actions, narrative descriptions, symbolic representations, socioeconomic and cultural factors and typologies/categorisation. Raubal et al. (2004) propose a framework to integrate affordances with time geography in support of LBS. Their aim is to allow services to better account for spatial and temporal dependencies of people's activities. Kuhn (2001) investigated methods for generating ontologies that account for how people distinguish geographic entities according to the actions they afford. As he explains, "For example, we consider a road to afford the activity of driving to a human being in a car (standing, in this combination, for Gibsons 'animal')" (p. 617). They demonstrate how natural language documents can be analysed as a basis for developing ontologies by identifying verbs describing actions and the nouns that afford these. The actions are then ordered into conceptual hierarchies by considering how one action entails performing another first. They demonstrate their method on the German traffic code, and in other work the EU Water Framework Directive (Soon and Kuhn, 2004).

2.2.3 Space

Blaut (1999) cautioned researchers in geography not confuse the two different ideas of 'Space':

> "The first meaning is the idea of space as *scale*, as the size of geographical or environmental places and processes. The second is the idea of pure space; spatial structure; form-at-a-timeless-instant; the idea of space as (naive) *geometry*." (p. 510)

GIS has often been accused of this making this very mistake (for a review see Schuurman, 1999). GISystems deal with things – ontological representations and concrete models of space. The focus is much more linked to how the world looks, *form*,rather than how the world works, *process* (Goodchild, 2004a,b). It provides a framework for a spatial science that allows analysis of information in terms of its spatial dependencies, and how these are manifested as intensities and arrangements of phenomena (O'Sullivan and Unwin, 2003).

As such, geometry does hold a privileged role in GIS, because it provides an effective apparatus to quantify, describe and analyse the world from scales and perspectives that cannot otherwise be apprehended directly. Since geometry may be described mathematically it is also ideally suited to encode data for representation in computers. However, there is a danger that GIS is seen as only about geometry and thus that the tool becomes substituted for the phenomena it seeks to represent (Fisher and Unwin, 2005).

LBS largely depend on GIS for their the spatial viewpoint (Boothby and Dummer, 2003; Shekhar et al., 2004). Because the abstract view of space is necessarily detached from its material origins, a practise can develop in LBS that too readily disembodies it from its human dimensions. This issue is of concern, because they need to be relevant to the activities and experiences of people (Reichenbacher, 2005). This issue is further exacerbated because, in general, the information available for servicing through LBS have been captured for quite unrelated purposes, resulting in fundamental mismatches (Dias et al., 2004b) between the geographic perspectives of the different stakeholders involved in collecting, formally modelling, and utilising spatial data (Couclelis, 1999).

Space as a Thing in LBS

For the most part in LBS, location is an essentially spatial concept. Space is represented absolutely using a spatial reference system that allows positions to be indexed, organised. This provides the most simple and straight-forward method for linking information and the user, since it can then be detached entirely from its material setting and co-related using only a distance metric. This is the model that has dominated location-based search in LBS, for example to answer questions in the form "Where is my nearest . . . ?" using a radial search propagated from the user's position (Boothby and Dummer, 2003, c.f.).

Space has also been viewed extensionally in LBS, describing the spatial range of actions and interests. In this approach, different types of information and activity are bound to scale dependent extents which determine the *spatial scope*. A number of researchers (Edwardes et al., 2003b; Reichenbacher, 2004; Heidmann and Hermann, 2003) have suggested typologies of spatial scopes to organise activities. Edwardes et al. (2003b) describe these as: immediate surroundings, region of activity, and whole resort. Similarly, Reichenbacher (2004) suggests: immediate surroundings (micro scale), region of activity (meso scale), and background space (macro scale). Figure 2.2, illustrates the model of Reichenbacher (2004), which he has in turn adapted from Heidmann and Hermann (2003).

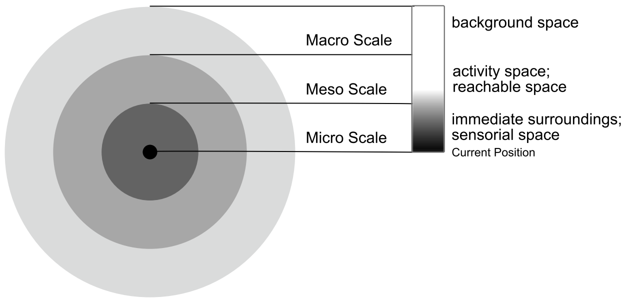


Figure 2.2: Spatial scope of activities, ((Reichenbacher, 2004, p.67) (adapted from Heidmann and Hermann, 2003, p. 126))

The problem with these models is that they don't differentiate between space as setting, space constructed by an activity and space as an objective framework for representing, analysing and presenting information indirect from experience . They suppose that such differences are dissolved by the scale at which geographic phenomena are considered. However, as Timpf et al. (1992) have discussed in the context of wayfinding, activities themselves can equally be represented hierarchically, entailing a breakdown of tasks at different spatial scales. Likewise, as medium for representing information and quantifying relationships, different spatial patterns and different abstractions of phenomena will have strong scale sensitivities.

Indeed, any map will serve dual roles of simultaneously describing differences between locations (Casti, 2005), in terms of objects and places, and describing spatial similarities in terms of spatial forms and relations. Map users will exploit these roles for different purposes. In the context of an activity, a map user will usually seek to imagine themselves within the map and relate the information directly to them or their future actions. In the context of spatial information, the attention will be on the located data and the user will necessarily need to separate themselves from the space in order to focus on the objective relationships. Hence, the naive geometry that Blaut (1999) describes comes about solely as a product of the imagination when viewing information from an indirect perspective. It is not a tangible thing but rather a framework of our minds in order to make sense of patterns. In doing so it necessarily devolves space from its material, cultural and often temporal foundations. It gains from this a means for quantifying phenomena (e.g. extent, volume, shape, intensity) and for describing space relationally (e.g. by proximal or directional relations).

2.2.4 Regions

Adjoint to the notions of space and place is often added that of *region* (Paasi, 2002; Montello, 2003; Curry, 2002). The relationship between the three concepts is highly ambiguous. Different authors have defined regions as spaces, or as sub- or super- concepts of place. For example a country is a place people live and identify with, a space bordered by a usually definite boundary, and a region having different properties like language and customs.

For Tuan (1975) regions are places, with each occurring at different geographic scales, e.g. fireplace, home, neighbourhood, town, city, region and nation. Tuan discriminates between places like regions and neighbourhoods and places like cities and homes in terms of their boundedness. Regions do not have the same perceptual or conceptual visibility as places. They “lack sharp, physically defined boundaries” (p.157) and exist “primarily in the minds of urban sociologists and planners” (p.158) and geographers (p. 159) rather than in the experiences of the people living there.

For Montello (2003) regions are a form of category.

> “Regionalization, the creation or identification of regions, is a subset of categorization. Categorization is the identification of discrete sets of entities, physical or conceptual. Categories delimit entities which share one or more properties from entities which do not share the properties.” (p. 174)

Geographic regions are a subset of regions generally, having the properties that they are spatial and usually defined according to their contents. Montello also follows the view discussed in Section 2.2.2, that place is a sub-concept of region. He proposes a taxonomy of regions that consist of four types: administrative, thematic, functional, and cognitive.

Representing Regions

One of the critical issues that Montello highlights is that of delimiting a boundary around regions due to inherent vagueness. This vagueness emerges for different reasons:

1. measurement vagueness – error or imprecision in measurement
2. multivariate vagueness – alternate combinations of variables
3. temporal vagueness – boundary changes over time
4. contested vagueness – disputed boundaries
5. conceptual vagueness – based on concepts that are already vague

In this view vagueness is intrinsically linked to the notion of boundaries. So part of this vagueness, in particular with respect to boundaries that are *fiat* (Smith and Varzi, 1997), comes about because of a need to spatialise cognitive categories so that they can be formally represented (Mark and Frank, 1996), when they are not mentally constructed as geometric entities. They are qualitative rather than quantitative and are better conceived as constructs of language (Talmy, 2000; Mark et al., 1999; Rosch, 1978) and symbolic reasoning (Tomai and Kavouras, 2005).

This view is evident in Geographic Information Retrieval (GIR) (Jones et al., 2001). Here the aim is to index web-based information to linguistically meaningful geographic terms, allowing people to search for information based on geography, for example "hotels in Zürich", where Zürich is on the one hand a place and on the other a *fiat* region. To achieve this GIR must construct a decomposition of space based on ontological categorisation of places (Jones et al., 2004). Location-based services can also benefit from this form of geographic model because it re-attaches location to a basis that is more meaningful to activities than that of a purely spatial representation (Edwardes et al., 2005a). There is still a necessity for spatial representation to realise the model for computation, which raises the issue of imprecision of location at boundaries (Purves et al., 2005). In part this can be handled by applying the satisficing principle of Hill (2000), other models for describing connectivity amongst regions have also been suggested (Schlieder et al., 2001; Brumitt and Shafer, 2001; Hu and Lee, 2004) as well as for defining inherently vague regions (Montello et al., 2003).

2.2.5 Space, Place and Region: A Reconciliation

Curry (2002, 2005) sheds some light on the confusion among the concepts of space, place and region. He looks at the historical roots of geographic thought through the classical triad of: *Topos*, *Choros*, and *Geos* (conventionally referring to place, region, and space). For Curry, these concepts are not "ontologically oriented oversimple conceptualizations of scalar differences, but, rather an outgrowth of epistemological differences" (Curry, 2005, p.680).

That is, they are not things, like geometric entities or spatial categories, but rather are different ways of understanding and memorising geographical spaces.

He analyses the development of the concepts, arguing that

> "each of those concepts can only be understood against the background of technologies available for the storage of knowledge, and for the representation and communication of the knowledge." (Curry, 2002, p.502).

In this respect, he describes how different mechanisms (e.g. memory, narrative, writing, mapping) have been used by people at different times in history to classify the world and develop knowledge about it. In the earliest chorography the positions of the stars in the sky were used as way of defining which region of the earth someone was in. These regions, 'klimata', had their own identities (e.g. the torrid, temperate and frigid zones) that differed in their nature and qualities. In topography, knowledge was structured and ordered by using narratives as mnemonic devices. These recited the experience of moving between places which were themselves described using signs awash with symbolic significance. Only the geographic made use of a spatial reference system, relying on mathematics to construct an image of the earth.

This shifted the focus from the ordering, meanings and qualities of places toward their extrinsic cartographic representation. The development of the geographic led to regions being bounded with areas and places that represented them, for example as points in space.

Discursive Displacement

This process of employing one perspective to represent another, Curry terms *discursive displacement*. It results in much of the ontological ambiguity in how the words space and place are understood in different topographic, chorographic and geographic contexts. Discursive displacement occurs most clearly between when a spatial framework is imposed on perspectives of place and region and in doing so produces a boundary that is not otherwise inherent in the way of thinking. Equally it can be seen when places are described as regions (e.g. a neighbourhood) or regions as places (e.g. a nation). Likewise in LBS, a spatial description of the position of a user is displaced as a location framed within the context of a place or region.

By expanding on space, place and region as ways of thinking an escape from the ontological confusion surrounding location can be conjectured. Curry's model thus potentially provides a very suitable general typology for considering geographic thinking and experience germane to LBS. Indeed, Curry has discussed the triad with respect to LBS though the focus was on the social and privacy issues related to the technology (see Goodchild, 2001).

Topos, Choros and, Geos

Applying these to LBS, the chorographic relates to how we organise the world as categories (Smith and Mark, 2001; Rosch, 1978) and we discriminate among areas based on different qualities and properties. Choros is thus manifest in how people see regions as providing different types of opportunities, for example nightlife, excitement, tranquillity or wilderness, and how people learn about the world and its phenomena, for instance as habitats and ecosystems. Likewise, it provides a context for modelling locational queries about information related to these types of activity.

Topos embodies the personal experience of the world. It is bound into human meanings and rituals such as dwelling, eating, remembering and socialising. It is created in the course of activities. Topos can be seen in the functions of LBS for searching and presenting information, for example as 'points-of-interest', and the representation of these by adapting them to be meaningful to a person and context of use. As Curry (2002, p.504) notes, topos is also evident in wayfinding directions where a route is organised in a narrative of landmarks demarking important actions.

Geos allows thinking about objects and places in the world in terms of abstract spatial relations and quantities. It allows organisation in an objective way and reasoning using a spatial logic. In LBS, geos is distinct in the dominance of the map as a primary interface, for example in the phrase "map-based mobile services" (Meng and Reichenbacher, 2005). As Curry discusses, "the geographic lacks the mnemonic underpinning that patterns of associations provided for the chorographic and the topographic. As a consequence, it requires a substantial medium for storage of content" (p.685). For him, the presence of a cartographic representation of places, as points, and regions, as areas, is necessary to organise and encode information in this form.

2.3 Re-presenting Geography for Mobility

Location based services are part of a class of technologies that need to look at ways to go beyond description of space and mediate within peoples experiences of it. This means they need to be able to account not only for the physical characteristics of locations but also how locations provide the context for action and cognition.

Place in LBS

The perspective of place offers a great potential in this regard since it unites concerns about activity with setting, issues that to some extent have been studied in LBS in isolation. However, place is not an easy perspective to represent. For the most part is an emergent property of space that develops through activity, interaction, and exploration. The spatial frameworks of location based services thus need to be able to support their users' in creating places more than in representing them explicitly. There are several ways that this might be achieved better.

Hybrid Spaces

Hybrid spaces that mix physical and virtual space have been suggested as one approach with three-dimensional augmented or photo-realistic representations being an example of these. These frameworks have the advantage that they provide representation that can be explored in similar ways to how the world is experienced. The main problems are that at the extreme they replace the world rather than sit side by side with it. In addition, for a mobile setting where the preferred method of interaction with a device is through short but frequent sessions of interaction (Ostrem, 2003) they can also distract to much from primal experience.

Tours

Tours and guides are a different method to represent the perspective of place. They have the advantage of a narrative form with is more closely related to the way in which places are remembered. Also, they can be relatively unobtrusive, for example using audio whilst leaving users visual senses free to explore. These do tend to represent places in more explicit ways as stopping point on a tour. They then support their users in adding meaning to these places by providing deeper contextual information. The disadvantage to the needs that will be described in this work (location based services in open spaces and protected areas), are that they can be over prescriptive in the places they describe and limited to particular routes. Hence the user has less freedom to explore space and create their own places through their spontaneous activities.

Cartography

Whilst in many ways the perspective of more traditional two-dimensional maps is ill-suited to needs for supporting place. They do also have a number of advantages. They are not constrained by particular paths and are relatively unobtrusive, allowing their users more freedom to explore. The difficulty of their use lies in how they are able to support the dynamic needs of users such as changing location and different interests and activities. Maps in LBS need to be seen as more of a single component within a wider system of presentation of geographic information. In this role they need to support the dynamic portrayal of information in response to the ever changing context of the user in ways that are sensitive to the physical location. This wider system needs to be encompass the full range of different geographical perspectives to define both how information is represented and how it should be presented to support myriad types of activity. In the next Chapter the observations made here will be drawn on in a practical setting; the analysis of user activities and user needs for information.

Chapter 3

Research Context

3.1 Webpark: LBS for Protected Areas

3.1.1 Project Aims

The WebPark project was a research and development project enabled through the European Commission IST programme (project No. IST-2000-31041). It ran between October 2001 and October 2004. Its overall objective was to:

> "identify the geographic information needs of mobile users, to provide to such users geographically relevant personalized location-based services (LBS) and to create new G-commerce value-chains for recreation/ protected area administrations and data integrators."(WebPark, 2001, p. 4)

WebPark therefore sought to develop a platform and suite of end-user services, together with related business processes, that would allow visitors access to unique environmental, cultural, historical and touristic information on mobile devices. Such content was to be largely drawn from existing data resources that had been captured by the park agencies and custodians for various commercial and non-commercial purposes such as research, education, and tourism.

WebPark aimed to leverage these data resources within a new computational framework that contextualised access and presentation of the information according to aspects such as; the location, time, personal interests and activities of visitors. In doing so, it sought to add value to the data resources for both the visitors and the park administration (Dias et al., 2004a). For the visitors, a more informed encounter with a region could be experienced. Their questions could be answered as they arose, activities could be better planned and organised, and the area could be explored in ways beyond what was immediately visible. Clearly, enriching the enjoyment for visitors of the protected area was of direct importance to the park administration. Additional value could also be obtained through a better return of investment for data collection, achieved by creating a new channel for information provisioning. This return could be financial, in the case where the services were run for a profit, or non-monetary such as by better attaining goals for supporting education and leisure.

3.1.2 Consortium

The WebPark consortium consisted of partners from industry; European Aeronautic Defence and Space Company, and Geodan Mobile Solutions, the sciences; City University London, the University of Zürich, and Laboratório Nacional de Engenharia Civil Lissabon, and from the national parks community; the Swiss National Park.

The industry partners were responsible for developing the technical infrastructure that supported services on the client, the server and between these. The Swiss National Park provided the perspective of the end-users both in terms of their visitors and their own needs as a host for the services. In addition, they provided rich content such as animal and plant observations, route descriptions, and point-of-interest (POI) information. The research institutes provided GIScience expertise for modelling, analysing and representing geographic information (Edwardes et al., 2005a). This included investigating questions related knowledge discovery (Mountain, 2006), the use of intelligent agents (Mountain et al., 2003) and dynamic visualisation on small displays with help of cartographic generalisation (Edwardes et al., 2005b).

3.1.3 Study Areas

The project focused on two main study areas; Texel and the Swiss National Park. The following descriptions are drawn from Gaaff et al. (2005) for Texel and Lozza and Cherix (2001) for the Swiss National Park.

Texel

Texel is the largest of the Wadden islands situated in the Waddensee off the coast of Holland. It has a resident population of more than 13,000 with an additional average of around 45,000 tourists staying overnight per day . A number of significant landscape types can be distinguished there including tidal flats, marshes, beaches, dunes (c.f. Figure 3.1) and cultivated land. The entire dune area is protected as a national park - 'The Dunes of Texel' and in addition various polders are protected as nature reserves.

The island is rich in flora and fauna. It is particularly well know for the variety of birds that can be found there, sometimes being called 'Bird Island'. In 2003 a total of 264 species were recorded by the Texel Bird Society.

Swiss National Park

The Swiss National Park is situated in the South-East Switzerland in the Canton of Engadine. The park is the oldest in Europe, founded in 1914 and holds International

Figure 3.1: Dune park in Texel (Copyright E.Dias)

Union for Conservation of Nature and Natural Resources (IUCN) level 1 protection, the strictest category.

The landscape of the park is dominated by mountains which range up to from 1400m (Clemgia gorge) to 3173m (Piz Pisoc). The park supports 3 main types of habitat; forest, alpine meadows and high alpine. Which support a wide variety of alpine flora and fauna.

The park has three main aims.

- Nature Conservation: No human economic activities are carried out in the park (e.g. hunting and timber)
- Research: Long term observations provide a unique understanding of the changes that are taking place in the National Park.
- Information: The national park aims to pass on much of its understanding to visitors to provide them with a better understanding of the environment.

The park receives nearly 150,000 visitors every year. In order to allow the park to persist naturally with a minimum of disturbance to animal and plant life, visitors to the park must follow a strict set of regulations: They many not leave the paths, they may not remove anything (e.g. flowers, mushrooms, berries) from the park, they may only walk (no skiing or cycling), they may not camp overnight in the park, and they may not bring dogs.

3.1.4 Project Outline

The project sought to innovate in four main areas (WebPark, 2001, pp. 11-13):

- Mobility – By creating services that could answer visitors' questions at the moment when they were most relevant, for example when the user was mobile and outside, and by providing information that would otherwise only be available from a static context, e.g. a CDROM, kiosk or over the Internet.

Figure 3.2: Typical landscape of the Swiss National Park (Copyright E.Dias)

- Ubiquity – The providing services available at any time and in any location, not dependent on the available technological infrastructure such as the mobile communications network.

- GI and Multimedia content business processes – The project needed generate design processes for the storage and handling, integration, and commodification of geographic content for location based services.

- Spatio-temporal intelligence in coastal, rural and mountainous landscapes – The service needed to be responsive to the context of use. Taking into consideration not only where and when the service was being accessed (position and time), but also what the user was interested in, the past and future space of their activities, and their personal preferences, for example for types information and language.

To accomplish these objectives, efforts were focused into seven workpackages, shown in Table 3.1.

3.2 User Needs for Information

An evaluation of user needs was carried out in 2001 at both the study sites. For the SNP surveys were sent out to 2420 address contained on the SNP database which included customers of the park shop and subscribers to the park magazine, “Cratschla”. In addition the survey was made available on the park website. In total

Work-Package	Title	Sub-Packages
WP1	Project management	-
WP2	Market and user surveys	Existing information services
		User surveys
WP3	GI standards and services	GI Interoperability and metadata standards
		Data services for demo
		G-commerce processes
WP4	Location-based service development	Personalisation
		Knowledge discovery methods
		Intelligent spatial agents
		Device dependent information display and generalisation
WP5	Architecture and delivery	Interface to geolocation services
		Web clients for location-based services
		Web portal
		Payment services
WP6	Validation and testing	User reactions to prototypes
		Trial LBS using scenarios
WP7	Dissemination and exploitation	Conservation safety agendas
		Evaluation, dissemination, and exploitation

Table 3.1: Work-Packages in the WebPark Project (WebPark, 2001)

1597 were completed. For Texel a similar survey was carried out using websites, and email as well as direct contact with visitors to the Texel nature centre, 'ecomare' and people taking the ferry to Texel from mainland Holland. A total of 179 were completed (Abderhalden et al., 2002).

The survey considered a range of issues including demographics, exposure to new technologies and digital media, use of media (e.g. maps and guidebooks) when visiting the sites currently, and preferences and needs for different types of proposed services (Abderhalden et al., 2002). Of particular interest to the work described here were these latter questions. Figure 3.3 reproduces the table of results on user needs for information services for the SNP by Krug et al. (2003). The results showed a strong importance was placed on information about safety and security, as well as a high demand for information about wildlife. In addition, information to support navigation was seen as desirable.

In Texel a similar picture of needs was apparent. Figure 3.4 reproduces these results from Dias et al. (2004b).

n=1000	% very important	% important	% less important	% not necessary		% no statement
3.9 Safety information such as severe weather warnings, unuseable paths etc.?	51.2	26.7	8.9	4		9.2
3.6 The locations of particular animal species and how to get there?	36.1	37.3	7.3	8.6		10.7
3.1 Maps and other information for orientation purposes based on your actual position (similar to the car GPS-system)?	20.5	37.4	12.8	17.2		12.1
3.5 Actual information about vegetation (e.g. important flowers in blossom)?	20.1	45.3	13.2	8.7		12.7
3.3 Thematic maps, for example geological maps, vegetation, slopes etc.?	15.4	45.4	16.3	10.4		12.5
3.7 Local information about current research projects?	8.7	40	26.5	11.9		12.9
3.2 Information on your route, such as quality, steepness, distances and narest/next picnic areas?	15	37.3	18.6	18.2		10.9
3.4 The nearest possibility of personal information?	12	34.6	26.1	14.8		12.5
3.8 A virtual, interactive instruction trail guided by a mobile/PDA?	2.5	19.8	28	35.4		14.3

up to 20%
20 to 30%
30-40%
> 40%
no statement

Figure 3.3: User needs for information in the Swiss National Park (from Krug et al., 2003)

Modal value

n = 77	Important	Nice to Have	Less important	Not necessary
i) Maps and other information for orientation purposes based on your actual position	38.0%	33.8%	14.1%	14.1%
ii) Information on tidal flats, mudwalking possibilities	33.8%	41.6%	10.4%	14.3%
iii) Information about vegetation and animals	16.7%	43.6%	24.4%	15.4%
iv) Local information about current research projects	7.0%	23.9%	39.4%	29.6%
v) Thematic maps, for example geological, tidal maps	16.7%	41.7%	18.1%	23.6%
vi) Safety information such as severe weather warnings, shelter harbours	62.5%	26.4%	2.8%	8.3%

Figure 3.4: User needs for information in Texel (from Dias et al., 2004b)

3.3 WebPark Services

The analysis of user needs lead to a focus on four principal services: mapping and navigation, point-of-interest search, geographic bookmarking and flora and fauna search.

3.3.1 Mapping and Navigation

Base maps provided a central focus for the suite of WebPark services. On the one hand, they provided topographic information for visitors to orientate themselves and navigate with. On the other, they supplied a spatial framework for integrating and presenting the many other the forms of information searchable by location or semantics. Figure 3.5 illustrates a series of maps for the SNP being used in the WebPark platform.

A second service supporting navigation was the 'trekking' service (Mountain, 2003b). This provided a view of a route as a height profile over distance or time. The service is illustrated in Figure 3.6.

3.3.2 Geographic Bookmarking

The geographic bookmarking service (Mountain, 2003a) allowed visitor to annotate locations at specific moments in time with their own personal comments. These bookmarks could be stored for future private use or shared with other users. The

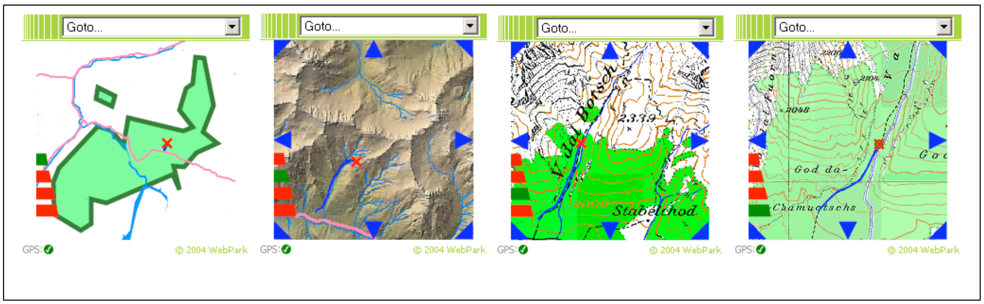


Figure 3.5: Topographic map series for the SNP

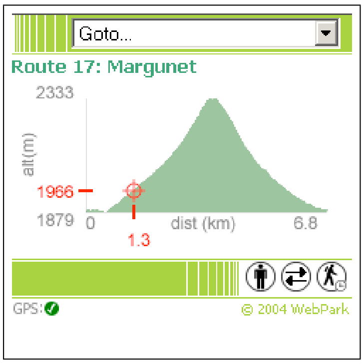


Figure 3.6: Trekking service

service had much in common with those with the GeoNotes (Fagerberg et al., 2003; Espinoza et al., 2001) and E-Graffiti (Burrell and Gay, 2002) described previously in Section 2.2.2. Figure 3.7 shows one of the interfaces of the service

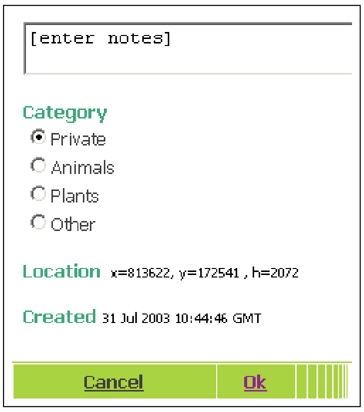
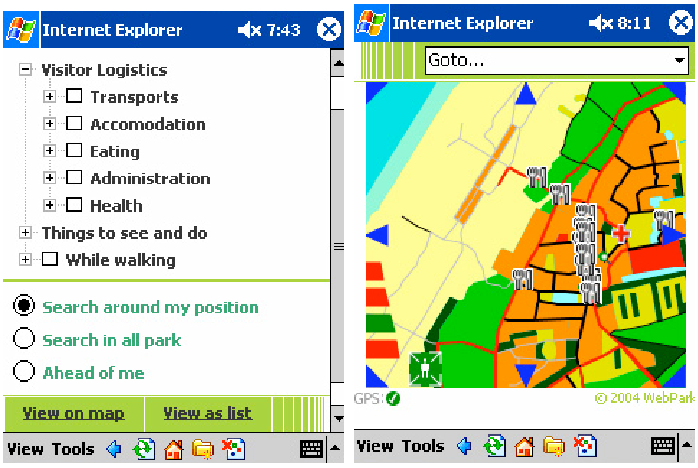


Figure 3.7: Geographic bookmarking service

3.3.3 Point of Interest Search

Point of interest searching provided visitors with the ability to look up services and places of interest to them, for example accomodation or somewhere to eat. Figure 3.8 show the points of interest search for Texel.



(a) Search interface (b) POIs displayed on map

Figure 3.8: POI search service for Texel

3.3.4 Flora and Fauna Search

A foundation of this thesis has been the creation of the flora and fauna service. This allowed visitors to access a variety of data sources related to the wildlife and ecology of a national park in a manner that was relevant to their questions and their context (location, time of use, and interests). The application also provided a framework into which park administrators could embed their data holdings, so that these can be published and accessed in a comprehensive way. Details of the flora and fauna search application will be described in the next chapters.

Chapter 4

Analysis of Visitor Questions

4.1 Introduction

The design stages of the WebPark project used a number of techniques for assessing visitor needs for information and services. These included an analysis of currently available information and substitution services (Dias et al., 2004b), surveys of regular visitors to the Swiss National Park visitors by mail (Krug et al., 2003), and *shadowing* of groups while visiting the Swiss National Park (Abderhalden and Krug, 2003). Part of the shadow monitoring involved recording questions made by visitors to park guides. The aim being to identify different types of information that are relevant to visitors such as geology, flora and fauna, navigation and landmarks and their spatial and temporal extent.

In this chapter, a further analysis of the questions related to flora and fauna is made. The aim is to better understand what sorts of questions visitors ask and how visitors conceive of geography and location in the process of interacting with and discovering their environment. The complete list of questions classified with the categorise developed through the analysis are listed in the Appendix A.

4.2 Related Work

In Chapter 2, a discussion was made of how geography in location-based services is increasingly presented in ways that are highly personal (Raper et al., 2002) and *ego-centric* (Meng, 2005). The difficulty encountered here was that conventional spatial models in GIS are not always the most appropriate for representing the geographical perceptions involved in this direct form of engagement. Because how people think about geography is internalised in ways that are difficult to access through introspection, methods for uncovering such experience must there be found as part of the design process (Lobben, 2004).

Suchan and Brewer (2000) describe a variety of qualitative procedures for informing the design process in contemporary map making. These include, verbal exchanges (e.g. questionnaires and interviews), direct observation (e.g. shadowing), and document analysis. den Hengst et al. (2004), in the context of mobile information services design, additionally introduce prototyping and model-driven design, i.e. starting with an information model. Table 4.1 draws on these typologies to describe different design approaches and give examples of their use from the literature.

Elicitation	**Methods**
Verbal	Questionnaires (Schmidt-Belz et al., 2003), interviews, surveys (Krug et al., 2003)
Group	Focus groups (Kaasinen, 2003), brain-storming (Brodersen, 2001)
Evaluative	Prototyping (Laakso et al., 2003; Kjeldskov et al., 2005), model-driven design (Dias et al., 2004b; Edwardes et al., 2005a), tracking (Dillemuth, 2005)
Cognitive	Thinking aloud (Paay and Kjeldskov, 2004), category norms (Smith and Mark, 2001)
Contextual	Participant observation (Brown and Laurier, 2005b; Tamminen et al., 2004; Abderhalden and Krug, 2003), conversational analysis (Perry et al., 2001)
Textual	Document analysis (Kuhn, 2001; Soon and Kuhn, 2004)

Table 4.1: Qualitative methods for designing map and mobile Systems

Whilst a number of different techniques were employed in WebPark to elicit user needs and evaluate alternative data, the focus here relates most closely to those employed for textual analysis. The aim is to develop an understanding of visitors' conceptions of their environment through the language of the questions they ask. The use of questions has the advantage that it relates well to the form of dialogue exercised by users in a session with a location-based service or a conventional map. Brodersen (2001) illustrates this in the context of map design, however his source of questions is obtained through introspection of the parties involved in commissioning a map. The main disadvantage is that questions tend to emphasise language based forms of interaction to the detriment of spatial ones. A visitor would ask a question expecting a spoken answer in response rather than a map. Hence to some extent the spatial nature of questions needs to be assumed or emphasised beyond what would be possible in the interaction.

The methodology to achieve this shares much in common with the document analysis of Kuhn (2001) and Soon and Kuhn (2004). They suggest the need for analysing user activities when creating ontologies of geographic domains (Agarwal, 2005). They use natural language texts, the German traffic code and the EU Water Framework Directive, describing actions as a basis to ground conceptualisations. They focus on the actions (verbs) described in the texts and how they are afforded by domain objects.

Their technique consists of the four basic steps of:

1. Selection of text describing relevant domain activities.
2. Extracting the actions from the text, denoted for example by verbs and verbal expressions.
3. Extracting the subjects and objects afforded and affording these actions.
4. Order actions by lexical entailment (i.e that one action must precede another).
5. Create an action hierarchy describing the theory of the domain. (Kuhn, 2001, p.626)

The method also has similarities with qualitative research methods for content analysis (Boyle, 1994). These seek to identify categories (codes) in a text corpus and often summarise the frequencies of their occurrence. Their method differs from conventional content analysis in that it goes beyond just analysing the words' semantics and also considers the syntax of the words as having ontological significance, i.e. verbs equate to actions and and nouns to objects affording these. This methodology is followed here but is adapted to needs of the generating theory suitable to inform application design and to take into consideration the aspect that the data is composed of questions and are therefore interrogative acts. This is taken to mean that the question is soliciting information to support some form of activity (Groenendijk and Stokhof, 1997). Hence, essentially it is considered what kinds of questions are asked, what activities are afforded, how questions are posed, and what constitutes an answer.

The aims are therefore to investigate a set of questions:

- "What kinds of questions do people ask?"
- "Are different modes of geographical thinking evident in the expression of location, i.e place-based, spatial and regional?"
- "What activities are suggested by the questions?"
- "What constitutes an answer to the questions?"
- "How can the service design be informed by the question analysis?"

4.3 Methodology

The methodology draws on the stages described by Kuhn, but is also influenced by the procedures and terminology of content analysis and *grounded theory* (Pidgeon, 1996).

Grounded theory is an inductive, discovery-oriented approach from qualitative research. It provides a systematic method for developing theory bottom-up from data, most often textual documents. The theory that emerges consists of model of concept categories and their inter-relationships (Pidgeon and Henwood, 1996). The method iterates between collecting data, labelling and coding it into categories and memoing links amongst categories. Categories are then grouped, sorted and redefined in an iterative cycle. The approach here differs in that some initial salient categories independent of the data are assumed. For example, place, region, space, action. Grounded theory instead derives all its categories directly from the data. In addition, only one stage of data collection was performed in this analysis whereas in grounded theory data is continually developed as the theory develops. The main part of the approach employed was the coding, categorisation, grouping and re-categorisation.

The methodology employed consisted of four main stages shown in table 4.2.

Step	**Procedures**
Data Preparation	• Sampling data relevant to the situation and application • Organising and labelling questions so they can be indexed and sorted
Initial Analysis	• Coding data into categories
Core Analysis	• Memoing links and entailments amongst categories • Splitting categories, grouping and sorting questions • Inferring intentions
Outcomes	• Answers to research questions • Application design considerations

Table 4.2: Main stages of methodology for analysing visitor questions (after Pidgeon and Henwood, 1996)

Kuhn's method can also be seen in these steps. The identification of actions as verbs and affording objects is comparable to the process of coding concepts. The core analysis relates to the identification of entailments amongst actions. The ontology resulting is the model or theory that is produced as an outcome.

4.4 Data Preparation

4.4.1 Selection and Classification of Questions

For the analysis a set of questions that visitors had asked researchers during the shadowing monitoring (Abderhalden and Krug, 2003) is used. Because the questions covered a broad range of environmental subjects, it was necessary to identify a relevant sample. Since the ultimate objective of the analysis was to develop a location-based service answering questions about wildlife, questions not about flora and fauna were rejected, e.g. geology. This resulted in 115 questions that provided a basis for a general model for the service, as well as real user input against which the service could later be evaluated.

4.4.2 Data Storage

To support the analysis process, each question was printed out on an filing card. As well as numbering the question, this included two sections of fields. One related to the categories described by Kuhn: action, affording object and subject that afforded the action. These focused directly on the question. An open section of other potential codes was also provided, to note categories related to the intentions behind the question. Figure 4.1 illustrates a coding card.

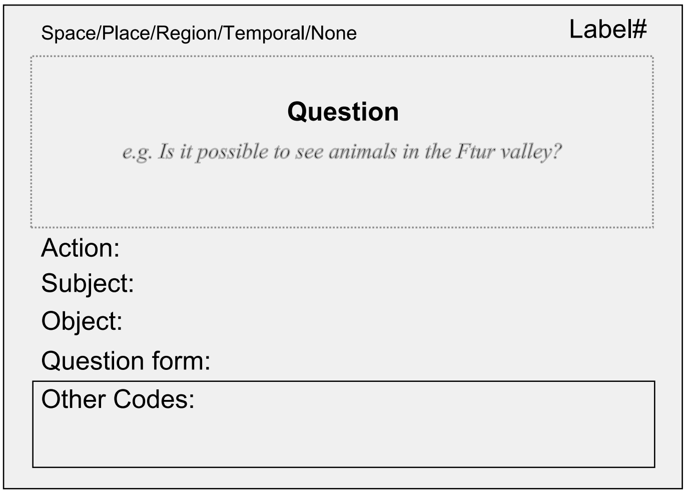


Figure 4.1: Card used to code a question.

4.5 Data Analysis

The cards were used to document a broad set of codes based on subjects, objects, actions. Analysis was then transfered into a spreadsheet, where the codes were laid out against the questions. Analysis proceeded iteratively, by proposing different grouping categories for the codes and questions, filtering the set to focus on one category and examining the fit of this category to the codes. To improve the fit the category could either be re-named, split or joined with another category previously examined.

The rest of this section describes the outcomes of this analysis and an interpretation.

4.5.1 Actions

Tversky (2004) discusses the two different senses in which people think about function, one for living things and another for artifacts. For living things function relates to servicing their needs and wants. For artifacts it relates to their use by humans. However, in the question sample, people thought about wildlife in both senses. As living things, questions related to functions the environment played for nesting, providing habitat etc. As artifacts, wildlife provided functions to people such as being observed, being identified etc. The actions associated with people suggested their activities were motivated at two different cognitive levels, either concerned with actively exploring the environment or with constituting knowledge and understanding. Actions were therefore split up into two groups according to whether they related to the visitor or a wildlife entity. Within each group one of 5 more general categories was used to classify the questions. Table 4.3 describes the actions in these categories.

Human Actions	
Visitor Actions	Finding, observing, seeing, passing
Categorisation	Naming, calling, being a kind or example of
Qualification	Relating importance or prevalence
Quantification	Relating extension (e.g. how big)
Park Management	Problems, research, conservation (stocking, clearing)
Wildlife Actions	
Animal Relations	Predator-Prey (e.g. hunting), Breeding
Animal Behaviour	Nesting, making a noise (e.g. singing)
Habitation	Living, occurring, staying
Life-Cycle	Hibernating, blossoming, being released, ageing
Causation	Causing, producing, making

Table 4.3: Actions related to spatial questions

Within the group of visitor actions, in Table 4.3, actions such as ‘finding’ and ‘observing’ implied an active form of exploration, for example stopping and searching for wildlife with binoculars. In contrast, the actions ‘seeing’ and ‘passing’ supposed a more passive and temporally continuous exploration, an awareness of what species to ‘look-out’ for. Such an opportunistic mode of exploring was also emphasised through phrases in questions like, ‘Is it possible…?’ and ‘Is there a chance…?’.

Categorisation was a more cognitive action directed at identifying and discriminating amongst concepts. Quantification and qualification were more tenuous categories. They captured questions that described properties and relations amongst categories that were more abstract than those described in 'Wildlife Actions'.

Wildlife actions grouped a wide variety of questions about behaviour, relationships, and life-cycle dynamics of plants and animals in the park. Amongst the most interesting questions in geographic terms were those related to habitation, since these questions relate locations, often the visitor's, to the presence of different types of species. There are similarities here with the action of finding, e.g. "Can marmots be found on Stabelchod as well?" is semantically very close to "Do marmots occur on Stabelchod?", the main difference is finding assumes a temporal component, related to the current moment of a planned activity, while occurrence does not. The other categories suggest the need to provide rich descriptive information about species, that is inter-linked according to inter-species relationships.

4.5.2 Subjects and Objects

The treatment by Kuhn (2001) of subjects being afforded actions is quite brief in that he only needed to distinguish one type of object, car drivers (p.623). Likewise, Soon and Kuhn (2004) filter out subjects that are not actors from their analysis (p.304). In the question sample, subjects could be the visitors themselves, e.g. "Will we pass it (the tree line) on our way?". In which case the question usually contained both direct and indirect objects (i.e. 'it' and 'our way'). More commonly subjects were things that had been observed, e.g. "Is this an alpine rose or a rhododendron?", defined by indexical pronouns such as 'this' and 'these'. The objects were either a kind of species, e.g. bird, or a location. Often these are being replaced with indexical or interrogative pronouns (e.g. what, where).

4.5.3 Granularity in Wildlife Semantics

Different levels of *kinds (types, universals)* (Smith and Mark, 2001, p.601) were used by visitors categorising wildlife subjects and objects. These ranged from simply 'Animals' to individual species names. Table 4.4 illustrates examples of these at different levels. Following the discussion by Smith and Mark (2001), Table 4.4 categorises the kinds hierarchically using taxonomic classes roughly equivalent to some of those found in the Linnaeus classification, Kingdom, Class, Family and Species. Rosch (1978) proposed that in such taxonomies there is one level of abstraction that people most commonly use. This she terms the *basic level*. It represents a cognitive trade-off between two opposing goals. On the one hand, the need for an abstraction with rich enough semantics to be sufficiently informative. On the other, the need to minimise the total number of categories. In Table 4.4 candidates for basic level categories have been underlined. Those highlighted occur multiple times in the question sample. It is interesting that the categories Red and Roe Deer, Ibex, Marmots, Golden Eagles and Bearded Vultures crop up many times in the questions despite

Kingdom	Class	Family	Species
Animals	Birds	Tits	Alpine Jackdaws
		Woodpeckers	Jays
			Mountain Pipits
			Alpine Choughs
			Bearded Vultures
			Golden Eagles
	Reptiles	Snakes	
		Frogs	
		Ants	Bark-beetles
	Fish		
			Marmots
			Ibex
			Chamois
			Red/Roe deer
			Bears
			Wolves
			Lynxes
	Trees	Pines	Mountain Pine
		Deciduous trees	Larches
	Flowers	Rhododendron	Alpine Rose
			Monk's Hood
			Edelweiss
	Grasses		
		Lichens	
		Berry bushes	

Table 4.4: Categories used for describing wildlife - basic level categories underlined

being at the species level. The park is well renowned for these species implying that to some extent form a general set of basic level, prototypical categories of park animals. This is also evidenced by the lack of any other term grouping such species, for example ungulates, eagles or birds-of-prey.

There was also a clear change in the level of semantics used in relation to the type of action. Visitors commonly used species level semantics when attempting to verify the name of the species or locate it, e.g. "Is this flower called alpine rose?" or "Where do the alpine jackdaws nest?". In identifying a species or asking about occurrence more coarse semantics were often used, e.g. "What species is this frog?".

4.5.4 Locations

Places often formed the objects of a question. The distinction between places and regions and spaces is delayed until Section 4.6. Since, in a natural environment their are few entities with crisp, well-defined boundaries, visitors needed to describe and name places in a variety of ways. Table 4.5 classifies these in direct and indirect categories according to whether they related immediately to the visitor's situation or if they were being used to locate remote regions.

Experience	Category	Examples
Direct	Surroundings	'here' (explicit or implicit), 'up here', 'in this area'
	Activity spaces	'on this trip', 'on our way'
	Individual features	'this meadow', 'this side of the valley', 'this moor'
Indirect	Named places	'Ftur Valley', 'Stabelchod', 'Val Trupchun', SNP
	Topographic kinds	'forests', 'creeks', 'southerly exposed slopes'
	Habitats	breeding sites, nesting sites, burrows, release sites

Table 4.5: Types of places

'Here' was the most frequently used term to denote a location. In conversation it provides a very simple referent so long as the meaning is understood by both parties, the visitor and the researcher in this case (Tversky, 2002). Outside this context it is highly ambiguous. In the analysis, this ambiguity was both a reflection of the data collection method, passive recording of visitors questions, as well as on the underlying ambiguity of location that needs to be considered in an LBS (Schlieder et al., 2001). The distinction between implicit and explicit used in Table 4.5 refers to whether the word 'here' was explicitly used by the visitor or whether a question implicitly refers to the current surroundings, such as 'Are there. . . ?'

Activity spaces are the slice of the park that visitors expected to experience through the course of their activities. They are spatial, relating to the region accessible from a path, as well as temporal (Miller, 2003), both in the sense that they represent a future experience and a trip which will unfold in time (Raubal et al., 2004).

Identified features are individual places that were both described using topographic descriptions and directly identified with an indexical term such as 'this'. By distinguishing a feature the visitor disambiguated possible interpretations. Therefore, the context shared by the visitor and the researcher was made much more explicit. One issue with these types of features is that they can simultaneously be viewed as objects in the environment and parts of the environment. For example, a meadow is generally thought of as a place and a tree as an entity, even though in different contexts both could be thought of as places, for instance in terms of functioning as ecosystems. This might also suggests the use of different kinds of image schemata in each case, for example object and container (Mark and Frank, 1996).

Place names are a common method people use to refer to locations (Jones et al., 2001), even though their referent may be inherently uncertain, for example a mountain (Smith and Mark, 2003; Fisher et al., 2004). When using place names, parties assumed a common basis of regional knowledge between them, in order to recognise the locations referred to. Hence, the use of 'Swiss National Park' (SNP) provided the ultimate common reference frame for any spatial question.

Indicating kinds of locations using topographic classes allowed a visitor to ask more general questions about wildlife-environment relationships, for example, "Do the marmots also live in the forest?". They provide a mechanism for ordering information at a more general level than is provided by making questions about single features.

In referring to habitats, the visitor was essentially defining places functionally according to the affordances they provide e.g. for sheltering. Often this usage was related to 'Where...?' questions, e.g. "Where do the birds breed?".

In many questions there was no spatial entity. This was particularly the case in questions that related to observations, e.g. "Is this also a gentian?". Here places can be seen as being created by perceptual acts, and hence provide settings for the actions and experiences, i.e observing, hearing and understanding, without themselves being explicitly defined.

4.5.5 Question Types

A number of general canonical forms to many of the questions could be identified. Table 4.6 itemises these.

The questions 'What x is this?' and 'Is this an x?' both attempt to identify a perceived individual by associating it with a kind. Questions in the first form are termed *constituent interrogatives* (Groenendijk and Stokhof, 1997), since they enquire about the properties (constituents) of an entity. They seek to specify the pronoun 'what' through a top-down approach to identification, where a category at a higher level of abstraction e.g. kingdom, class, family scopes the definition to lower levels e.g. species. Questions in the latter form are termed *polarity interrogatives* (Groenendijk and Stokhof, 1997). They elicit a yes or no answer in response to a category suggested at a fairly detailed level (e.g. family or species). The two strategies potentially suggest different design choices for LBS interfaces. For example, by drilling down through a taxonomy tree or by presenting groups of basic levels.

The questions 'What x can be found in y?' and 'Are there x in y?' likewise represent the two different types of interrogative sentence. The aim of these questions is to associate entities with different types of place again using the level of semantics as a control.

Questions of the form 'Where can x be found?' are also constituent interrogatives. They differ in that they use an interrogative adverb to enquire about the

Form	Examples
What x is this?	Which bird is singing there? What species is this frog? What kind of tree is this? What kind of a flower is this? What droppings are these? What kind of tracks are these?
Is this an x?	Is this flower called 'alpine rose'? Is this a true ant-hill? Is this dropping from a red deer? This whistle is made by the marmots, isn't it? Are these all marmot holes?
What x can be found in y?	What tit species occur here? Which animal species can be observed on this trip? What are the main tree species of the SNP? What flowers are there still in blossom?
Are there x in y?	Are there any marmots here? Are there mountain pipits in Val Trupchun? Is there a chance to observe a golden eagle on this trip? Can marmots be found on Stabelchod as well? Are there roe deer up here?
Where can x be found?	Where do the alpine jackdaws nest? Where do the animals stay usually? Where do the birds breed? Where were the bearded vultures released?

Table 4.6: Categorisation of canonical question forms

conditions surrounding a verb, in the case of 'where' the location of the action. Hence, these questions seek to associate entities related affordances to the environment.

4.5.6 Temporal Questions

A perhaps surprising observation was that only one question used the temporal adverb 'When' ('When did the [bearded vultures] releasing start?'). In spite of this, several questions had a temporal component, for example questioning past events. It can also be argued that almost all spatial questions have an underlying assumption of time though it might not be expressed. This can be seen in the model of Sinton (1979), who suggested that each of the three components of geographic information, location, time and theme; behave in one of three roles that is as a constant, a control or a measured variable. Which component performs which role differs according to the application. This idea can be usefully applied to the questions. For example in the question 'Can marmots be found on Stabelchod?', the location 'Stabelchod' is fixed as a constant, variation in marmots is being queried and the current time of year, implied by context, is acting as a control. So, if the question was asked in the early summer the answer might differ to that in the late summer. If the question were to be posed 'When can marmots be found on Stabelchod?' the roles of time and marmots would swap, marmots would be the control and time the variable. If instead it were made into "Where can I find marmots?", then location would be variable, marmots the control and time would be taken as constant. Hence, although the (spatial) questions may not explicitly include a temporal term they may imply it, in which case time is a control, or they may omit it, in which case it is taken to be constant.

Where time was explicitly mentioned in question different temporal models were used. Table 4.7, categorises these using the typology for models of time described by Frank (1998). Temporal components are underlined. Similar to the discussion

Temporal Model	**Examples**
Ordinal Time	When did the [bearded vulture] releasing start? How many animals are radio-tracked in the SNP at the moment? Are all these stumps remnants of the last woodcut?
Interval Time	How long does the decomposition of dead trees last? How old are these trees? Which further animal species can be observed on this trip? Is there a chance to observe a golden eagle on this trip? What flowers are there still in blossom?
Cyclic Time	Have the marmots already started hibernation? Can animals be watched depending on the time of day? Do the red deer have a certain daytime activity? Is this grass regularly cut? Is there fog here so often?
Branching Time	Will these dead trees be removed some day? Have there been living bears / wolves / lynxes in this area?

Table 4.7: Temporal components of questions

of spatial questions, temporal components were either predicates that constrained the scope of the questions ('at the moment'), or they related to the type of answer that was expected, for instance 'How long . . . ?'. As with temporal questions time was associated both to direct experience, for example their own temporal context or in relation to the context of the activity ('on this trip') being performed, and to the behaviour of wildlife or changes in the environment. Polarity and constituent distinctions could also be made.

4.5.7 Inferring Interrogative Acts

Based on observations described in the previous sections, questions could also be categorised by inferring the intentions behind the act of asking it. The nature of a question usually involved the a visitor seeking to create knowledge by starting with a piece of information or conjecture and seeking to verify this or link it to another piece of information.

Conceptual Domains

Based on the discussion in Section 4.5.2, the different types of information could be broadly categorised into one of four domains:

- *Kinds* – these related to an ontology of species and associated concepts such as droppings and tracks. Kinds had associated descriptions related to the nature of the type of species, e.g. its behaviour.

- *Descriptions* – these are closely related to kinds, providing more detailled background information and enriched semantics.

- *Percepts* – these were objects related to perceptual experiences, such as something observed or heard. They were either directly encountered or assumed to be possible to observe at a future moment.

- *Locations* – these were geographic entities, such as the visitor's current location, a named place or a spatial distribution.

Different interrogative acts related these as knowledge forming links. The category of the act differed according to the direction the knowledge was formed in, e.g. kinds-to-percepts and percepts-to-kinds. Figure 4.2 illustrates the relationships.

Interrogative Acts

Referring to Figure 4.2, *identifying* sought to give a name to something that had been observed, whereas in *verifying*, the visitor had an idea of what the thing being observed was and sought to clarify this. Observations are always made in some place even if this is very subjectively defined. On the one hand, the action of *observe* linked known places with the chance to see certain entities, for example, "Is it possible to see animals in the Ftur valley?". As such *observe* can be directed, for example '*look* at this'. On the other hand, places represented a setting that influenced what was encountered and why, making place a form of context. Here, *observe* represented an active from of discovery and exploration. The action *situate* related the observation to this setting, for example "Why are there only pines here?". In this sense locations are seen as possessing certain functions and properties, such as providing habitats to certain kinds of wildlife. The action *occur* related a location to wildlife types in the absence of an observation, for example in the question "Do Ibex occur here?".

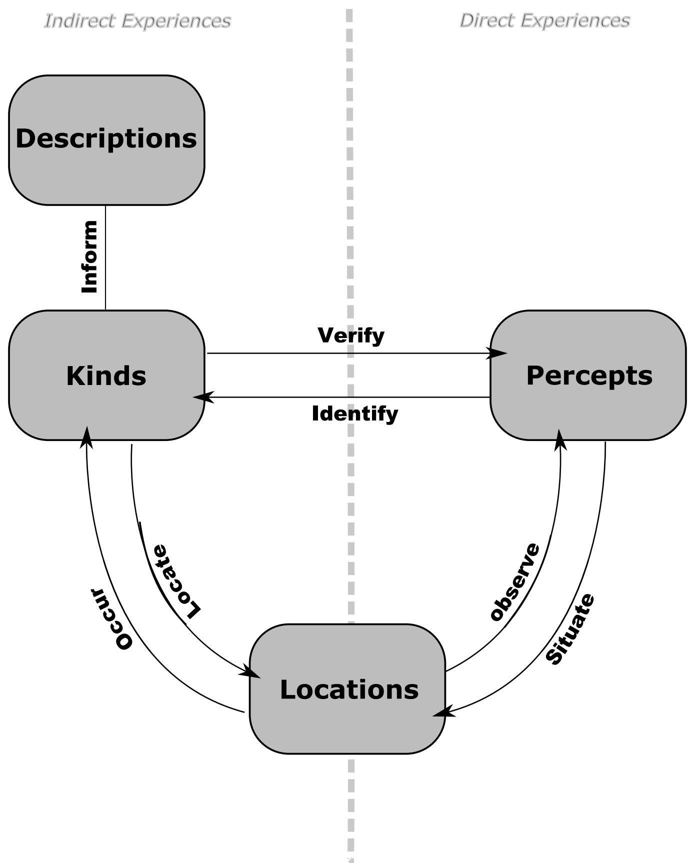


Figure 4.2: Actions forming links between conceptual domains

Occur, allowed the visitor to qualify characteristics of their location in terms of kinds. *Locate* sought to identify areas where a wildlife entity could be found, for example "Where do the animals stay usually?". *Locating* might also seek to find out if a certain kind of wildlife was in a known place, e.g. "Are there mountain pipits in Val Trupchun?". In this sense *locate* and *occur* are very close, however, the direction is implied by the level of semantics used, e.g. "Are there mountain pipits in Val Trupchun?". *Inform* related kinds to descriptions, for example related to the behaviour, relationships and life-cycle of a species.

These actions might be compared to those listed by Reichenbacher (2004): locating, navigating, searching, identifying, checking (p.69). His locating and identifying compare favourably to *locate* and *identify* respectively. Searching involves aspects of both *occur* and *observe*. Checking, which he defines as 'checking for events; determining the state of objects', doesn't have a clear fit though it might overlap to some extent with verifying and situating. Questions related to navigating were not part of the sample selected so this is largely omitted. Though arguably, *observe* involves navigating in the sense that sequences of objects and places might be encountered in the course of an activity.

Chaining Actions

Reichenbacher (2004, p.70) suggests that actions can be joined in the construction of an activity. He gives the example of the activity of going to the cinema involving searching (for films), locating (a cinema), checking (film times), and navigating. The same might be supposed for the actions defined here. The activity of bird watching might involve; searching for bird occurrence (occur) or locations where birds have been seen (locate), encountering a bird (observe), identifying the bird (identify) and finding out about its behaviour (inform).

In this way, the model is not limited to wildlife and the natural environment. *Percepts* might be objects of interest to a user, such as historic buildings, bars, or decision points and landmarks for navigation. *Kinds* could model types of things (e.g. restaurant or entertainment facilities), or at a finer granularity their actual identities (e.g. the name of a bar). *Descriptions* provide more detailed information about a kind, for example that museums are closed on Mondays. *Locations* might be defined by regions such as districts (e.g. historic, downtown) or by physical features such as roads.

4.6 Geographical Thinking

The aim of this section is to qualify the questions in terms of the predominant forms of geographical thinking evident, based on the analysis made and the considerations outlined in Chapter 2. The purpose is to provide definitions that guide considerations for designing and implementing a location-based service and ultimately show why such geographical considerations are important.

It is clear that classifying a question as spatial, regional, or place-based requires more than just a consideration of the type of locational entity or predicate. It needs to also consider the nature of the actions both contained in the question (Section 4.5.1) and implied by it (Section 4.5.7). In this way it also implies the form of information that constitutes an answer to the question.

Spatial forms of understanding were not related to direct experiential encounters. Instead, they sought information about wildlife that can be used to enhance and integrate knowledge or inform future activities. The most basic form of spatial question were those that only requested descriptions of locations, e.g. "Where do the alpine jackdaws nest?", or distributions such as "How big is a marmot population?". More sophisticated forms suggested spatial relations amongst entities, e.g. example "Do ibex and chamois occur together?", and topography, e.g. "Are the marmot lairs always exposed south?". In terms of Figure 4.2, the acts of *locate* and *inform* are those that predominantly imply spatial forms of thinking.

Regional thinking can relate to direct or indirect experiences of space. It allows a visitor to ask questions about the qualities of a unit of space. In the question the quality was most often what animals lived in the region, for example "Are there mountain pipits in Val Trupchun?" and "Do Ibex occur here?". The region of the park also provided a scope with which to ask general questions about the park and the opportunities for activities, for example, “Is the animal stock documented in SNP?”, “What flower is there still in blossom?” or “Is it possible to see animals in the Ftur valley?”. In respect to Figure 4.2, the act of *occur* is one that exemplifies regional questions. To a lesser extent *situate* can use regional thinking to characterise observations.

Place-based thinking relates to direct experiences, actions and activities conducted in space. Places in this way are not usually explicit but are rather formed through the interactions with the environment. Questions relating to observations were the most common form of this. Here, the observation was performed in a setting that was often relatively unique to the observer and the set of events that came together at a particular moment, such as the blossoming of a flower or the passing of a bird. Often in these situations, the question implied asked about properties of the place that influenced the observation “Is this caused by fire?” and “Is there fog here so often, that there are so many lichens on the trees?”. The space of an activity also creates a place at a larger spatial and temporal scale encompassing expectations of the actions that will be performed on it, for example “Is there a chance to observe a golden eagle on this trip?”. Considering Figure 4.2, the acts of *verify*, *identify* and *situate* suppose a place-based way of thinking.

4.7 Implications for Design

Figure 4.2 presents a model describing the different methods that the visitors appeared to employ to develop knowledge and explore their surroundings. The nodal points of this model, that is, the locations, the percepts, and the kinds and their descriptions, are all aspects that might be represented in a location-based service. The difficulty is the degree of subjectivity and ambiguity found in each of these concepts limiting their definition. As was shown in Section 4.5.3, the type of categories and kinds people choose to ask about wildlife varies from individual to individual. Likewise, as discussed in Section 4.5.4, people have an implicit notion of the area around them – ‘Here’ – but it is very difficult to know the extent of this and how it varies according to factors such as activity and actions (Schlieder et al., 2001). The notion that locations as places are created through a harmony with action insinuates that they perhaps cannot be represented at all, as is indeed suggested by Thrift (1996) and Dourish (2004). Percepts are clearly the most unpredictable and subjective of these concepts they are essentially tiny snapshots of peoples’ experiences of the world.

On the other hand, it can be imagined that such issues can be tackled. A comprehensive model of kinds might provide a method to represent the wildlife in ways that are flexible to personal categorisations. Locations have limits not least defined by topography and perceptual boundaries that can be used in representation. Percepts are not entirely unforeseeable. Some things are more unique or more obvious than others and so more likely to be noticed, indeed it is often desirable to direct attention to such things. If something has been observed previously in a place it can be assumed that there is a greater chance it will be seen there again. Some places are also more likely to result in the observation of a particular kind of plants or animals.

The links between these conceptual domains relate to different forms of interaction. For example moving (changing locations) and observing things, and searching for information. They have the characteristic that the actions performed to move between any two domains are not symmetric. They depend on the direction of navigation, i.e. the action *occur* is used to go from locations to kinds whereas the action *locate* goes from kinds to locations. *Identifying* and *verifying* suggest people require different levels of semantics to be presented to use them effectively. *Occur* and *locate* imply different forms of spatial representation, regions and spatial distributions. These need to be related to visitors' locations and different kinds of wildlife. *Observe* and *situate* suppose that people are able to create places through actions and activities. These need to be supported to some extent. The situational aspects of places need to be represented so that these can be related to encounters.

Figure 4.3 describes a more set of architectural components that arise from out of the considerations shown in Figure 4.2. It consist of four representational parts.

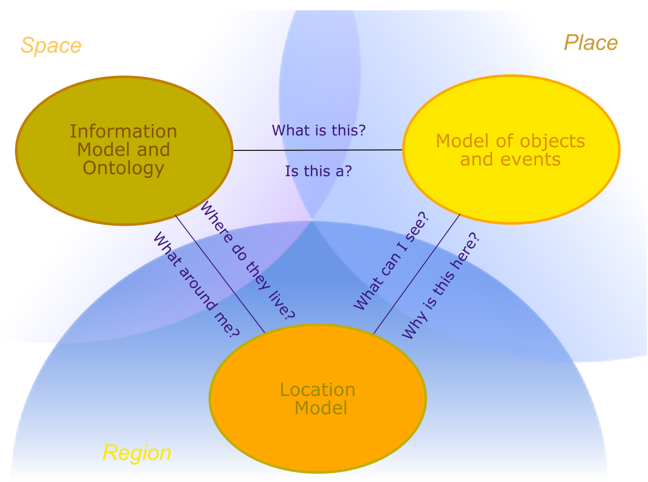


Figure 4.3: Model of conceptual domains and knowledge links making up the service

- A flexible ontology of wildlife kinds that can be personalised and presented in such a way that it allows encounters to both be verified using more detailed semantics and yes/no type interaction, and identified using coarser ones.

- An information model that complements the kinds with descriptions and spatial distributions of plants and animals.

- A regional model of locations that can be related to the visitor's position.

- An open model of encountering things that has both non-representational parts that support observation and interaction and a representational part that ties specific percepts to places.

Chapter 5

LBS Architecture

The preceding chapters set out theoretical issues for representing geography in location based services (Chapter 2)and described qualitative analysis of user needs (Chapter 4) with respect to the context of the WebPark project (Chapter 3). In the following chapters these ideas will be developed on through a description of techniques that can be used used in a mobile application, many of which were used to develop an application for searching for flora and fauna information in the WebPark project. The following chapters employ the model-view-controller paradigm from software engineering (Krasner and Pope, 1988) as a conceptual method to decompose the different components that come together in providing such a service. Here, the paradigm is briefly presented and discussed by way of an introduction to the chapters to come.

5.1 The MVC architecture

The model-view-controller (MVC) architecture is a *design pattern* (Gamma et al., 1995) frequently used in the development of interactive software. It decomposes an application into three main components that deal with how data is represented and accessed (the model), how information is presented visually (the view), and how interaction logic is defined (the controller). Figure 5.1 reproduces a model from a software engineering by Krasner and Pope (1988). In this figure, the model is responsible for the state of the part of the application under consideration, this could be as simple as an integer value (the model of a counter) or something more complex. The view represents everything that is graphical. It uses access data from the model and then displays this using it own abilities to perform rendering operations. The controller monitor user interactions and interface between model and the view in response to these. Interaction amongst these components is via messages which are broadcast in response to events.

The approach of applying the MVC pattern for mobile cartography has been discussed in Edwardes et al. (2003b) and Reichenbacher (2004). These approaches diverge from the software engineering one in treating the MVC architecture more as a

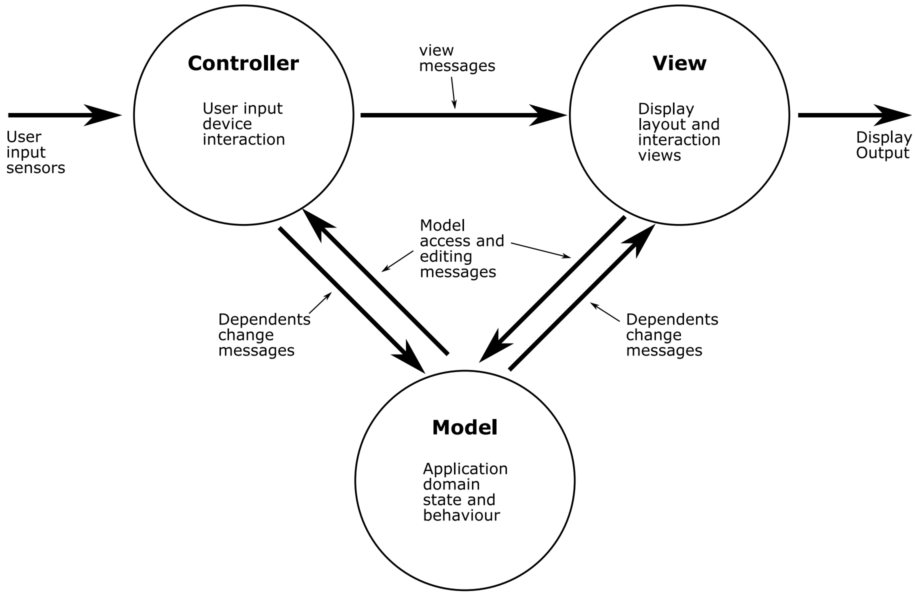


Figure 5.1: The MVC architecture as defined in software engineering, from Krasner and Pope (1988, p.27).

conceptual framework for designing applications. The description of Reichenbacher (2004) is perhaps the closest to the conventional definition. He uses the pattern to define how graphical adaption of map contents and symbolisation is performed in relation to changes in the user's context and activities. Figure 5.2 reproduces this model. Dynamic control is performed within his model by *adaptors* that relate data

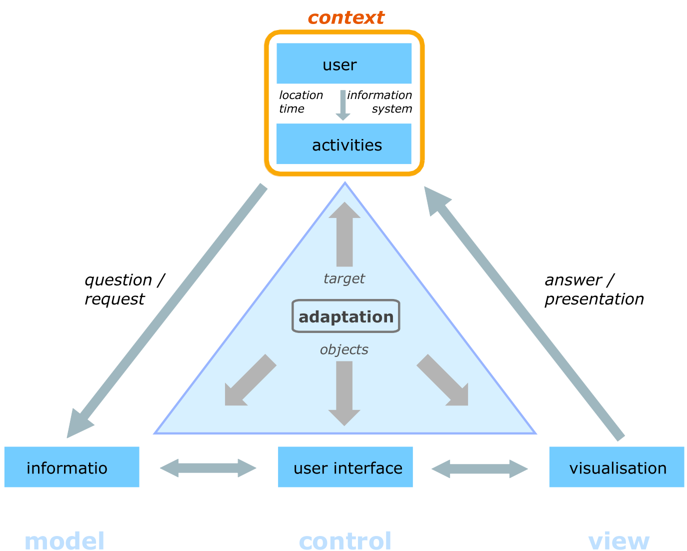


Figure 5.2: The MVC architecture from Reichenbacher (2004, p.62) for adapting maps in mobile cartography.

entities (*adaption objects*) to their graphical depiction (*adaption targets*) (Reichenbacher, 2004, p.60). There are strong similarities between this approach and that described here, the main difference is that Reichenbacher's concern is more with mobile services that are highly dynamic and require little user interaction. Here the application will have a fairly high level of interaction though dynamic presentation, essentially implementing an adaptor, is also described in Chapter 8.

The description of MVC in (Edwardes et al., 2003b) is a prototype of that used here. Figure 5.3 reproduces this model. The approach there compares LBS archi-

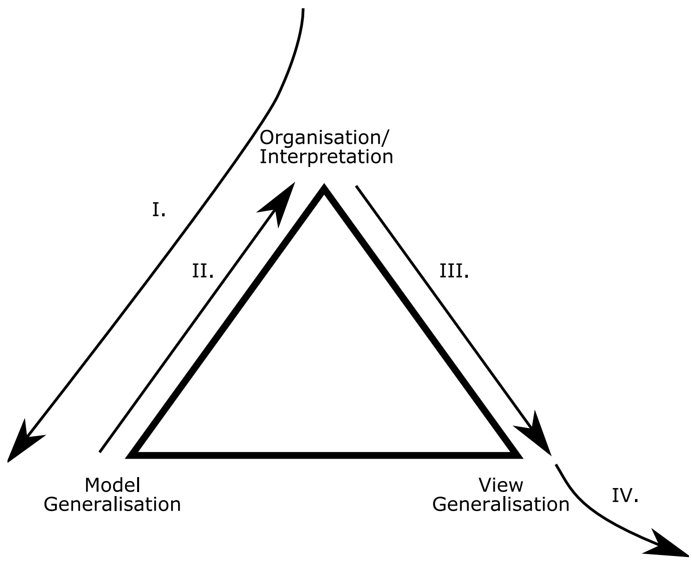


Figure 5.3: The MVC model from Edwardes et al. (2003b, p.1020) for generalisation within an LBS architecture.

tecture to the model of cartographic generalisation separating the generalisation of a "digital landscape model" (model generalisation) from graphical generalisation for the visual portrayal of a "digital cartographic model" (Brassel and Weibel, 1988), and attempts to extend it to the needs for dynamic cartography in LBS. It starts (I. in Figure 5.3) with an interpretation of the users question and the selection of an appropriate scale in an automated way or driven by the user. Depending on these factors the available information is accessed through model generalisation components (II.). The organisation and interpretation component then directs the creation of the final map (III.). It interprets the purpose of the map with respect to a model of the question being posed and fetches the data appropriately formatted to the relevant scale and considering what is important to be shown in the map by organising the data into significant groups. Finally it gives the structured data with directions for generalisation operators to the view. The view (graphical) generalisation (IV.) follows cartographic constraints and has the purpose of make the presentation of the spatial information legible. The functions here can be subdivided into two classes of operators. The first to try to reduce the amount of data due to space limitations and violations of design constraints. The second class to rearrange and reposition symbols to improve legibility.

5.2 MVC as a Conceptual Model

The MVC paradigm is used here more as a conceptual device for organising the work into logical units than to refer to underlying methods of implementation, though these did largely use MVC in the engineering sense. As such, the use of the terminology is slightly different to how it is used in software engineering.

The model is used here to refer to the activities involved in structuring data for deployment in a location based service. This includes a consideration of how available data holding are made relevant to the needs in a mobile environment and how they are technically harmonised within a central data model. In addition it is concerned with how data are made accessible to location based searching by data modelling and data access mechanisms.

The controller is taken to relate to all aspects of user interaction and the organisation of interactive components to achieve this. This draws on the analysis conducted in Chapter 4. In the conventional sense the controller would largely only be concerned with the underlying logic executed in response to user interaction and not the interactive component used, which would be part of the view.

The view is taken to mean map as a dynamic interface (Kuhn, 1991) and mechanisms by which geographic data are portrayed. Portrayal can be understood as encompassing a broad range of actions that result in the presentation of information "in a form understandable by humans" (ISO-19117, 2002, p.1). Here it is taken to include all the logic required to allow the map interface to dynamically transform the presentation so it best satisfies the requirements for effective graphical communication. To some extent this agrees with the conventional definition of a view in that it is expected that a view possess the necessary logic to rendering itself, though more usually this would relate to operations such as simple transformations and clipping. Mainly the second type of graphical generalisation operation, the re-organisation of foreground points-of-interest, is developed in this regard.

Chapter 6

Model: Data and Location Modelling for LBS

6.1 Introduction

The *model* in the MVC approach encompasses the issues that relate to the structuring of information so it can be accessed by the controllers during various patterns of user interaction. Three main problems are apparent when considering the model:

1. How can available data resources be evaluated and modelled to fit with the interests and needs of users?

2. How can data be structured, transformed and stored to allow it to be easily explored and be most expressive?

3. How can access to information be made relevant to the context of its use and mode of thinking?

The first question relates mainly to the use and integration of existing data sets to meet the user needs. In this Chapter these needs will be taken from observations made in Chapters 3 and 4. Question two is more practical. It relates to the technical issues of data modelling and data handling required to store and make information available both in a database and on the client device. Question three emphasises the difficulties of modelling location and the geographic perspectives that this entails. Again, this Chapter makes particular reference to the design of an LBS for searching for flora and fauna to illustrate and explore these challenges.

6.2 Evaluating Data for WebPark

6.2.1 Available Data

Many authorities for protected areas are responsible for the collection and dissemination of information about their natural and cultural assets. Mobile information services can support such responsibilities by providing channels through which to access data holdings in geographically meaningful ways. In the initial stages of WebPark a number of potentially useful sources were identified (Dias, 2002; Haller, 2002). Table 6.1 summarises the holdings most relevant to the flora and fauna search application for the two study sites.

-	**SNP**	**Texel**
Topographic	VECTOR25, PK25 - vector and raster data at 1:25,000 PK50, PK100 - raster data at 1:50,000 and 1:100,000 VECTOR200 - vector data at 1:200,000	TOP10vector - vector data at 1:10,000 TOP250vector - vector data at 1:250,000
	DTM10, DTM20, DHM25, RIMINI - digital elevation models at 10, 20, 25 and 250 meter grid resolutions	AHN - digital terrain at 5 meter grid resolution
	Bus lines and stops; parking places	Services of interest from the Texel tourist board.
Categorical	Geomorphology Forests Vegetation	Geomorphology Land-Use/Land-Cover Soil
Descriptive	National Park CD-ROM (Lozza and Cherix, 2001)	The Vleet CD-ROM (Gaaff et al., 2005) ETI Birds of Europe CD-ROM (ETI, 2003)
Empirical	ung_census - ungulate Census data (regional counts) ung_spadis - seasonal counts in 2 areas (point observations) shl - observations of rare species by rangers	
Derived	pot_ornis - habitat suitability maps for 38 songbirds	

Table 6.1: Summary of data holdings relevant to flora and fauna application

Whilst the data covered a broad spectrum of topics, the main problem was that they were generally not in a state in which they can be made readily available to users of an LBS (Dias et al., 2004a).

6.2.2 Evaluation Framework

The reasons for this are well illustrated through the framework of Raper et al. (2002) for evaluating geographic information (GI). This model distinguishes between components of GI that are representational, at the levels of ontology, modelling and system; and communicative, at the levels of relevance, exploration, commodification and management. Table 6.2 uses this framework to describe the issues related to existing data resources encountered in the WebPark project.

	Level	Issues for available data holdings
Representational	Ontological	Entities were represented within data holdings using differing abstractions, classifications and taxonomies for similar or related information.
	Modelling	Diverse spatial and aspatial (e.g. multimedia) data models were employed amongst different resources, with few or no geo-referencing relationships between them.
	System	A wide variety of data formats and media were used to store data (e.g. CD-ROMs, databases, documents).
Communicative	Relevance	Data had been collected for assorted dedicated purposes, for example research or inventory, and were generally mismatched to the information needs of ordinary LBS users (Dias et al., 2004a).
	Exploration	Data were not structured or indexed in ways that made them easily adaptable to location or other context based exploration. Data models were ill-suited for supporting readability, comprehension and visualisation, for example through multiple representations, generalisations or hierarchical abstractions.
	Commodification	Data were not organised in chunks easily distinguishable as information products. Copyright issues related to using data within information services had usually not been considered.
	Management	Data holdings were largely decentralised and often purchased or produced for one-off purposes making management and update difficult.

Table 6.2: Data considerations within the evaluation framework of Raper et al. (2002)

6.2.3 Harmonisation

One of the main conclusions of the initial information audit was that there was a clear mismatch between the information currently provided by the Park and the visitor information needs (Abderhalden and Krug, 2003; Dias et al., 2004a). The more integrated, descriptive and for visitors high-value information, usually contained little or no spatial information. In contrast, the more specialised research based information, such as the observation data, was highly spatio-temporal but ill-adapted to the needs of visitors for more general purposes. For example, the SNP produced CD-ROM (Lozza and Cherix, 2001) contains over 800 high-quality photographs as well as detailed texts, videos and sounds. Part of the richness of this resource are the numerous links amongst the different pieces of information providing the ability for users to explore questions related to particular phenomena. A particular challenge was then, how to design a model that would both ensure information was spatially explorable as well as maintaining the inter-connections amongst pieces of information.

Researchers on the GUIDE project (Cheverst et al., 2000) encountered a similar problem. Their solution was to define separate models for locations, containing places of interest and connections to travel between them, and for information consisting of hyperlinked cultural and historical media. The two models were then linked through the identities of places they had in common. This solution worked well for them because their primary interest was with places, with the system guiding their users between these. Thus their location model and entities of interest could to large degree be treated as the same thing. Our problem differed in that the entities were wildlife categories. Hence, the focus of interest were not inherently spatial phenomena but rather kinds of things, for example red deer. The precise locations of instances of these could generally not be predicted since they were usually non-static. A nature park is after all not a zoo, and animals range over space and, to some extent, plants appear at different times in different places. A similar model to Cheverst et al. (2000) was therefore followed, i.e. using separate location and information models, but explicit representations were additionally needed for entities which could provide a link between the two. This would allow the visitor to come to the information either through semantics related to the wildlife category or by their location. Our own solution directly enriched the model of wildlife entities with descriptive characteristics and hyperlinks referencing the identities of related entities. The entities then became the main data chunks, around which other services could be commodified (Edwardes, 2003). This organisation of information provided a high level abstract model, and compares with the model described at the end of Chapter 4. Figure 6.1 illustrates the model conceptually (species model) and logically (feature model).

The evaluation framework suggested a range of issues that needed addressing to harmonise data resources and make them available through this model. To meet these needs a series of information processing and management strategies were formulated. These activities can be viewed from two inter-related perspectives, as a sequence of processing operations transforming the data in differing ways, and as a set of data states (data structures and data models) and interfaces across which these are converted. Section 6.3 describes the activities from the perspective of a work flow of processing regimes. Section 6.4 describes the viewpoint of a set of data states and transitions.

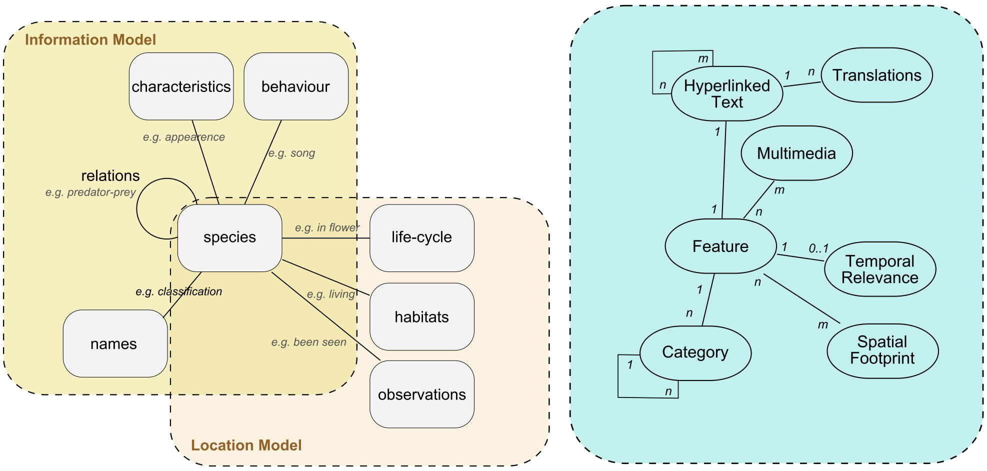


Figure 6.1: Abstract and logical feature models

6.3 Data Processing

The WebPark system and related processes could be simplistically viewed as a publishing tool that allowed intense information sharing of local knowledge with visitors to the park. To provide added value for the visitors, the information already available played a crucial role. Hence, GI and multimedia content needed to be adapted or created in order to meet the required accuracy and expectations of the visitor.

The GI content for the WebPark services could be initially divided into *background* and *foreground* information (WebPark, 2001, p. 12). Typical background information included topographic base maps and terrain data. The purpose of this data was to orientate the user and provide an information framework for embedding the more volatile foreground information. Foreground GI consisted of ephemeral information that could be explored by visitors according to their interests at a particular location and moment in time. Such content included information about flora, fauna, and points of interest (POIs) together with their associated geographic (e.g. animal distributions) and multimedia information (e.g. photographs and text descriptions) and would be modelled within the framework of the information model.

A review of the entity types found within the foreground information together with the analysis described in Section 4.5.3, provided a definition of species that should be searchable through the service. Information could then be managed and indexed using this model.

In order to prepare GI content for WebPark, an extension to the Extract, Transform, Load (ETL) process (Vassiliadis et al., 2002) was defined. Figure 6.2 illustrates the extended process.

The workflow can be considered as a linear process starting with the determination of available datasets (information audit – described in Section 6.2.1) and ending

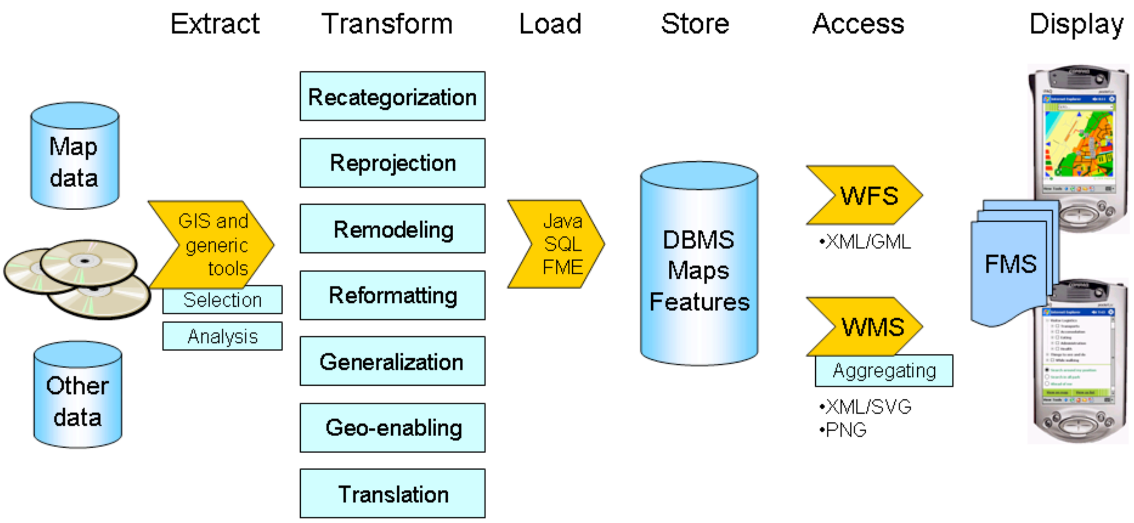


Figure 6.2: Data processing flow in WebPark (Edwardes et al., 2005a)

with the display of information to visitors. In the extraction step (detailed in Section 6.3.1) data was drawn into the workflow from its original storage medium. The step also involved the analysis of the data in order to select a spatially and semantically relevant data subset. Transformation entailed a set of operations necessary to harmonise and standardise the data according to the WebPark abstract data model. Extraction and Transformation were supported by intermediary data structures either using Java or intermediate database tables to facilitate their operation. The final step loading (Section 6.3.3) involved the persistent storage of the transformed data in the WebPark data model both in a database or content management system (Data Content Model), and on the device (Application Data Model).

6.3.1 Extraction of Data

Each physical data source had its own data model and system of classification, relevant to its original purpose and method of collection, its own data format (e.g. shape, dbf, jpeg), and its own storage medium (e.g. CD-ROM, database, text file). Hence for each data resource a process needed to be performed to harmonise it to within a set of common, uniform states. The main aim here was to harmonise the format and media that the data was stored in (the system level of Table 6.2). Different processes needed to be applied according to whether the data was to be managed primarily through an organised system of directories and files (content management system) or within the database.

Implementation

Data for the content management system included multimedia files (image, video, audio) and hyper-text pages. Whilst the primary mechanism for storing and organising this data was a file system it also needed to be related to information contained in the database. This meant that a system of classification needed to be defined to organise filenames and directory structures so that files could be later referenced by the database entries. To ensure all multimedia data was in a format supported by the WebPark services architecture (ultimately a format supported by the client device) a certain amount of reformatting of files was also necessary at this point, for example using image processing software. With this organisation in place these files could be copied and renamed to their appropriate places on the content management system file system, bringing them onto a single storage medium.

Data to be stored in the database consisted of text files, exported database files and GIS datasets. To load this data into the database it needed to be extracted into a common computational framework that could interoperate between the different data formats and the database. Java was used as a neutral mechanism to perform this. On the one hand, it provided a comprehensive encoding for representing data items and their associations as in-memory data objects. This meant that the loss of information semantics could be minimised during the import process. On the other hand, it provided a flexible framework both for integrating tools to read diverse data storage types as well as for interacting with the single database over Java Database Connectivity (JDBC) (Reese, 2000; Ellis et al., 2001) and SQL (Lorentz and Gregoire, 2002).

Different levels of organisation within the data led to slightly different processing regimes. Data which was loosely organised, for example contained in text files needed recategorising into specifically designed Java classes. Data that was already organised in entity-relationship type structures (objects, data records and tables) used classes with database type abstractions that mirrored the logical models of the data storage in the source medium. Primitive data types of the source data (e.g. text strings, dates and times, and integer and floating point numbers) were translated into equivalent Java ones. Readers where written or obtained for GIS data stored in shapefiles with associated dbf files and dbf files with geometries stored in x and y columns, text data stored in dbf tables, and plain text files containing descriptive information.

An example of this process was extracting data about birds (text, images, sounds, and video recordings) from a CD-ROM guide (ETI, 2003). Here a plain text file contained a set of entries separated by empty lines, with each entry containing the bird name, characteristics and description in a single language. Figure 6.3 illustrates the extraction process.

The extraction here used two classes, one based on the TextFileImporter interface and the other on the TextEntry interface, shown in Figure 6.3. The TextFileImporter interface defined the methods for importing a text file and returning a data structure that enumerates individual text entries. The TextEntry contained method descriptions for parsing individual entries. The associated multimedia files could be converted to appropriate formats, renamed and loaded into the content management system. References to these files were added to the new entries.

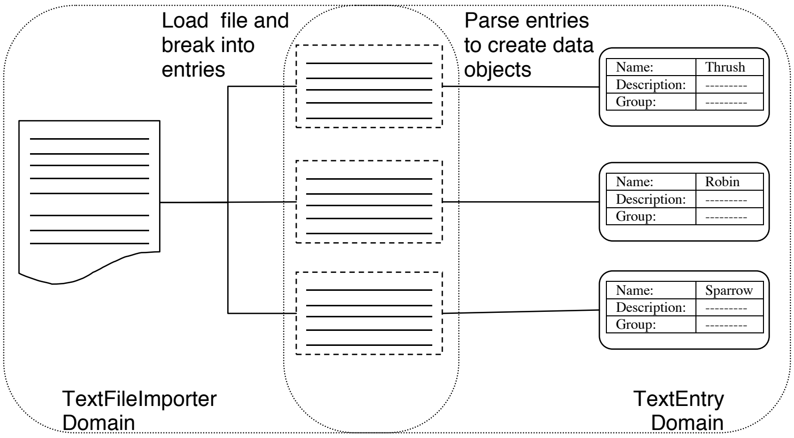


Figure 6.3: Extraction from a text file

6.3.2 Transformations

Depending on the individual datasets different types of transformation were required, see 6.2. These included:

- Recategorization - harmonising the conceptualisation of entities into a single domain ontology.
- Reprojection - reprojecting spatial data into a common spatial reference system.
- Remodelling - mapping the different sources data models into a WebPark one that allowed access in a context- and location-sensitive way.
- Reformatting - converting the heterogeneous data formats (mime-types) for multimedia native content into the formats understood by the WebPark clients.
- (Model) generalisation - applying geometric processes such as line filtering, aggregating features that were too small or defined with semantics that were too detailed.
- Geo-enabling - creating associations between spatial and aspatial data
- Translation – Information was to be provided in English, French, German, Italian and Dutch.

Most of these processes can be easily mapped to the framework of Raper et al. (2002) shown in Table 6.2. Recategorization enhanced the usability of the information at the ontology level. Reprojection enhanced usability at the modelling level. Remodelling, improved the modelling (by unifying into a single data model) and the exploration levels (the common data model is designed for LBS use). Reformatting, described partly already in Section 6.3.1, acted at the system level. Model generalisation improved readability and comprehension of mapping and thus can be considered as enhancing the communicative experience of exploration. Geo-enabling helped at the relevance (by re-aligning data to user requirement) and commodification levels.

Several of these processing steps were methodologically demanding and so a complete description is postponed until later in this chapter. Recategorization largely involved harmonising to a single domain ontology discussed previously in Section 6.2.3. Remodelling and geo-enabling will be described in Sections 6.5 and 6.6, respectively.

6.3.3 Loading

The import process used the Readers described in Section 6.3.1 to bring the data into a neutral format based around Java classes. Transformation could be performed using these classes and the data then loaded into the database. Loading was either performed directly into the WebPark Data Model or into intermediate database tables. Data in these would then be transformed again and loaded into the final WebPark tables. This was to take advantage of processing tools only available on the database and is described in more detail in Section 6.4.1.

Figure 6.4 provides an overview of the basic process.

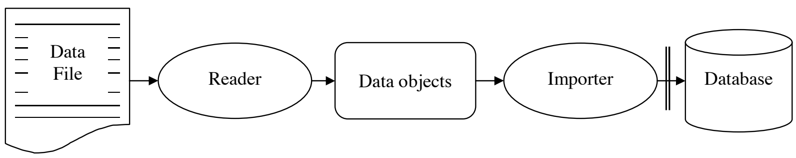


Figure 6.4: Loading Workflow

In the Figure, the Reader classes perform the extraction, the Data objects instantiate intermediate structures in Java for transformation and the Importer classes load the data into the database across the Data Import Interface.

Implementation

Figure 6.5 expands on the process by showing the associations between different types of involved classes. The purpose of the reader and data objects classes has previously been described. The database class provides an abstraction of essential database operations such as opening a connection, inserting data, executing a query, and committing a transaction. It provides a Java/SQL interface for interacting with the database. Figure 6.6 describes the classes and interfaces used for database interaction. Figure 6.7 describes a typical database transaction using these classes from a diagrammatic perspective and the implementation of this into code.

The database class itself used the singleton design pattern (Gamma et al., 1995). This meant there was only ever one Database object instantiated. The instance

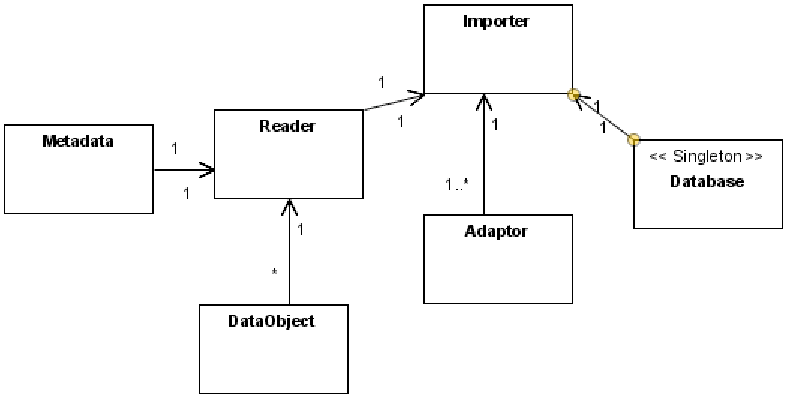


Figure 6.5: Types of classes involved in the ETL process

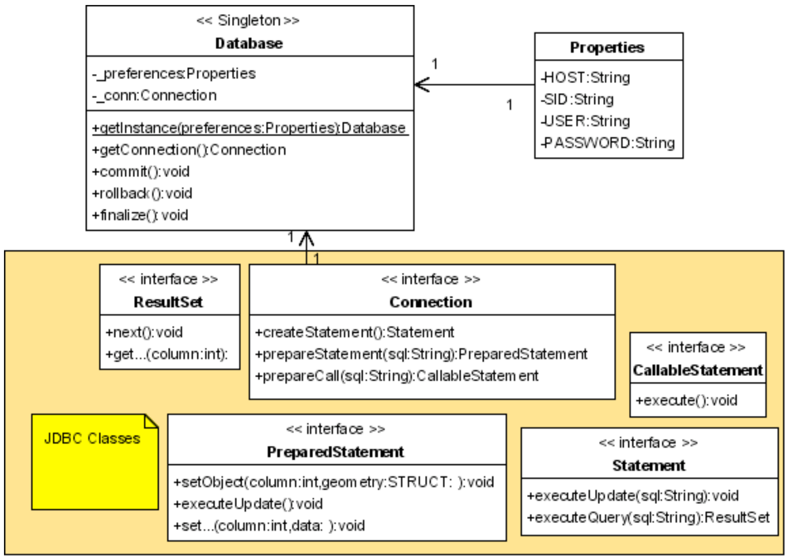


Figure 6.6: Classes for accessing the database

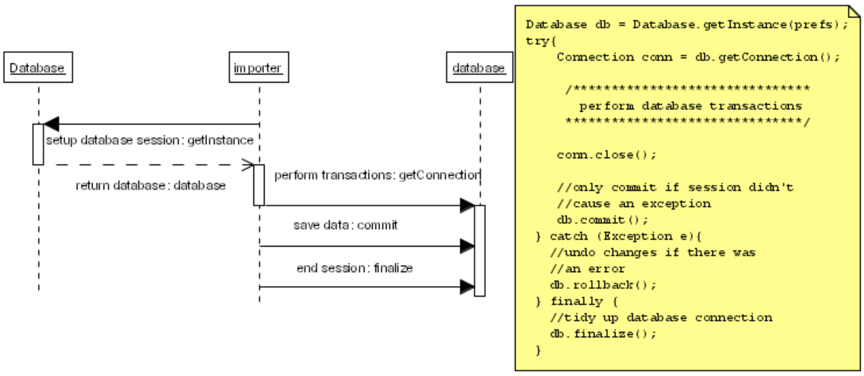


Figure 6.7: Typical database session

of Database was obtained through the static method getInstance() which takes a Properties object as its only argument. The Properties object encapsulated the data required to connect to a remote database with JDBC. Once a database had been instantiated a Connection instance could be obtained. This Connection provided the resources to execute database operations using SQL statements.

Statements were encapsulated within their own classes which differed slightly depending on the nature of the statement. In most cases a general Statement object for creating and dropping tables, inserting and updating data, and querying the database was used. This was obtained from the Connection using the createStatement() method. In particular cases other types of statement were required. PreparedStatements were used to insert complex geometric data and CallableStatements were used to call procedural logic residing within the database. Figure 6.8 illustrates the types of collaboration performed to add data to a database. To per-

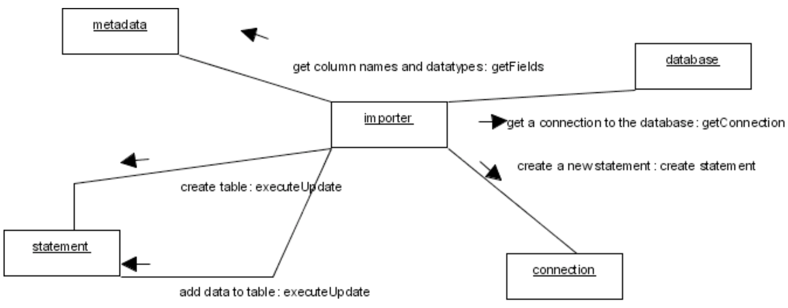


Figure 6.8: Collaboration for database interaction

form the actual interaction required by the import process SQL statements were constructed as strings and executed by the statement object.

Adaptors were used to convert between complex data types; spatial geometries are examples of these. In the import process geometries were stored and handled in several different formats that needed to be interchanged. For example, within the database geometries were stored in tables as spatial data objects (SDO_GEOMETRY (Murray, 2001)). When these were read into the Java framework or exported from Java into the database they were handled as SQL objects (STRUCT). Geometries read from shapefiles were represented as byte arrays. Adaptors converted between these various representations into objects based on a single set of Geometry classes. These were defined by the Oracle Spatial Java Library (sdoapi) (Murray et al., 2002).

6.4 Data States

The processing of foreground data could also be considered as a set of data states and points of data conversion performed within the WebPark architecture. Logically, these can be described as a set of data models and interfaces that transform between the models, with each stage of this decomposition having particular data processing requirements. Figure 6.9 illustrates the five main data states and three interfaces. In terms of the ETL process previously described, progress through this proceeds from right to left.

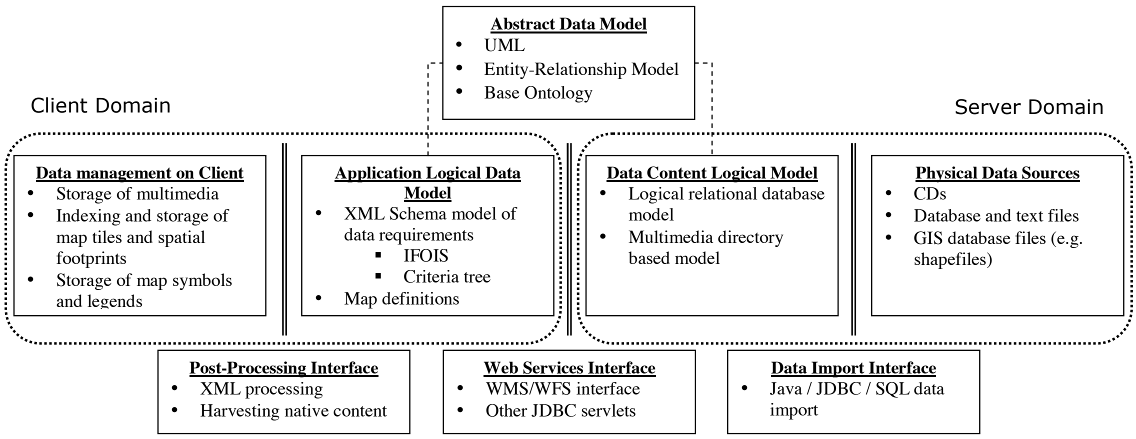


Figure 6.9: Data states and interfaces WebPark.

The "Abstract Data Model" has been described previously in Figure 6.1. The "Physical Data Sources" stage represented the basis data collected from the various sources described in Table 6.1. The "Data Content Logical Model" represented the data drawn from these resources compiled and organised in a neutral, logical model. This was stored within a single (object-relational) database or (file-system based) content management system. To achieve this, the data need to be processed across the "Data Import Interface". The WebPark services had their own data models designed to match the logic of the user applications and requirements of the client device. This is shown by the "Application Logical Data Model". Data stored in the database was transformed into this model across the “Web Services Interface”. The WebPark services were defined to operate seamlessly when the users is independent of an available network connection. This meant that all the data related to the “Application Logical Data Model” needed to be physically cached and organised on the mobile client device. The process of caching this data was performed through the “Post-Processing Interface”. The stage of “Data Management on Client” represents the cached state of the data on the client device.

6.4.1 Data Content Logical Model

Much of the spatial data that was loaded into the database was stored in initial database tables with schema that matched their source data models rather than the final WebPark ones. This was because subsequent transformation and loading was more effectively performed using database operations rather than being redefined using custom Java code.

Wildlife data was one example where remodelling was required. This was to:

- Coordinate all the separate data related to a single species. For example a species type might have spatial data related to its distribution, habitat preferences and observations, multimedia information such as calls, videos, photographs and drawings, and descriptive textual information. This process is described further in Section 6.6.

- Encapsulate information into (species) entities that could be indexed and searched spatially and textually.

- Aggregate and generalise spatial information to support different WebPark services.

- Manage multi-linguality issues, for example species names and descriptions using a single translation table.

Figure 6.10 describes the tables involved for modelling feature data such as wildlife information. As can be seen in the Figure, a separation was made between a species types, ‘features’, and their spatial occurrence, ‘footprints’. This separation was for a number of reasons:

- It needed to be possible to search and query the data both semantically and spatially (for example according to a user’s location).

- Depending on the question being asked different geographical perspectives where employed by the user (see Section 4) and accordingly different ways of modelling spatial occurrence needed to be considered, for example visibility factors might be more important than distribution if the user wanted to observe animals.

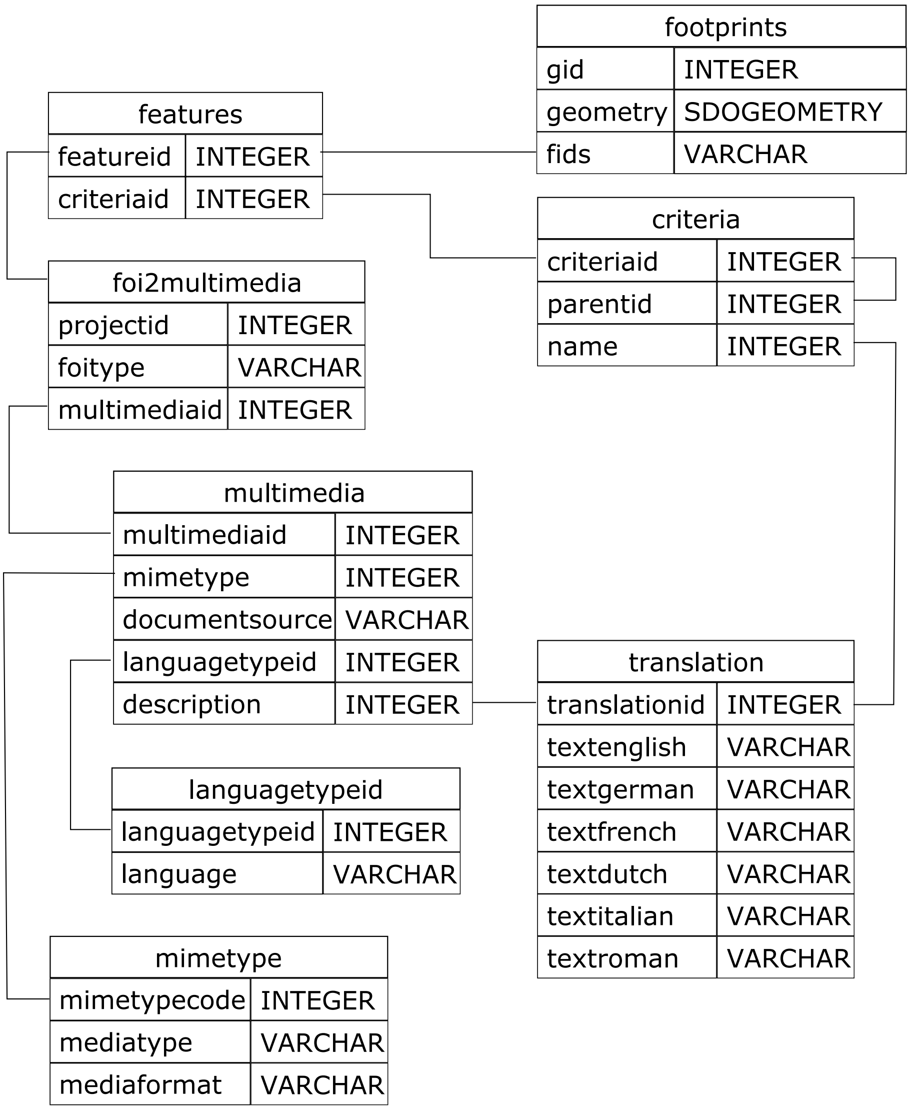


Figure 6.10: Tables and their relationships for wildlife data

- Different services had different criteria for *satisficing* (Hill, 2000) spatial requirements. By providing an entity as the focus different spatial representations could be used to model these. For example, spatial regions for indexing could be defined separately from spatial relationships information communicated as maps. Each form could be optimised according to its own needs on the device. For example, map data could be optimised for cartographic considerations (for example by generalisation) and regional data to be used on the client optimised to support efficient searching.

- The amount and type of data available on spatial occurrence of species differed markedly between areas and species. Hence the system needed different ways of describing the likely spatial occurrence of a species type (for example, habitat suitability, observations, density/distribution models, expert knowledge, home ranges etc.)

- The volume of data being held and analysed on the client needed to be minimised. The separation meant that data related to the type of species was only stored once, rather than once for each footprint.

Modelling spatial footprints of species is described in more detail in Section 6.5.

Categories of entities where managed using the criteria table. This was a self-referential table which could therefore allow tree taxonomies that structured semantics to be created. Leaf categories in the table related to the entities in the 'features' table. Parents of these related to different levels of abstraction. For example, part of a tree might be Animals⇒Birds⇒Birds of Prey⇒Golden Eagles, where Golden Eagles are a leaf category and the others parent nodes. Storing taxonomies in the database had the advantage that they were easy to update, manage, and base queries around. In addition, multi-linguality could be handled directly within the database in a common way with the translation table, described next. Whilst several classification schemes can be stored in the same table, the main disadvantage was that a tree is not ideal to model and operationalise many ontological relations that might be useful.

Multimedia was handled with the set of tables foi2multimedia, multimedia, languagetype, mimetype, and translation. The multimedia table recorded metadata about a data item as well as a reference (the documentsource column) to a specific file held within the content management file system. The foi2multimedia table linked these records to the features contained in a feature table. A table was used to model this relationship because it was many-to-many. That is, a single feature could have many pieces of multimedia and a single piece of multimedia could be relevant to more than one feature. Textual multimedia needed to be available in several languages. Therefore actual text was only ever placed in the translation table and this referenced accordingly by a key.

6.4.2 Application Logical Model

The application data model was defined as part of the portal design (Rhin, 2003). It comprised a data model defined in XMLSchema called the Integrated Features of Interest (IFOI) schema. This allowed XML to be used as the medium for transferring data entities onto the client and cached there. IFOI was based on GML (GML, 2004). As such, IFOIs were GML Features and their geometric data could be defined using GML spatial data encodings.

Features and footprint entities were mapped onto separate IFOIs with references between them. Textual information was embedded in IFOI attributes, likewise referenced to multimedia files. This meant that entities could be styled as HTML pages directly on the device, cleanly separating content and presentation.

6.5 Location Modelling

Location-based services were born out of the configuration of a set of technologies that had reached a sufficient level of maturity, availability, affordability, usability, and interoperability, that they could offer the potential to fundamentally change the way in which information is accessed and used in everyday life. Amongst these were positioning technologies (Roth, 2004; Grejner-Brzezinska, 2004) and in particular GPS. GPS had reached a point of technological maturity and commodification where reliable handheld receivers could be purchased universally at relatively little cost. These introduced the ingredient of location into the mobile information services that had been made possible by the convergence of other computing and communication infrastructure.

In the first instance, location was understood spatially to mean position. Through a common spatial reference system, point-based information could be inter-related, for example by Euclidean distance. This understanding of location was quickly found to be limited. For one thing, positioning techniques each have differing levels of accuracy (Spinney, 2003). This affects the way the position can be related to other information and therefore constrains the types of services the technique can be used for (Mountain and Raper, 2001). Secondly, a large amount of geographic information is either not available or not relevant as points, for example addresses and postcodes, buildings and their functional parts such as entry points, roads etc. Third, relationships based on point-to-point based geometric measurement are hard pressed when it comes to considering the constraints and barriers of the underlying geographic fabric of the space.

To address these issues location has increasingly come to be understood as position qualified in geographic terms. For example, by referencing it to a GIS database of features, e.g. roads, addresses, cities etc. Hence location and the relationships to other information become understood through a shared geographical embedding. To achieve this successfully means that the two domains must be bound by a shared *frame-of-reference* that unites the entities considered to be relevant to the user of an LBS (e.g. resources, services, people, places and events) with a set of locations where they can exist. Because they create a system of discrete inter-connected geographic entities, location described in this way can be seen as a part of the domain of ontology, or geo-ontology (Jones et al., 2004). Viewed in this sense, location is encapsulated by a form of thinking that is based around the categorisation of geographic entities. This moves location modelling from being fundamentally spatial to concerning the definition of regions (Purves et al., 2005; Montello et al., 2003; Vögele et al., 2003).

Whilst regions can be structured to support numerous forms of qualitative spatial relationships (Galton, 2001), for example 'part-of', 'in', 'north-of' and 'near', applying them to structure the locations of activities is problematic. Part of the reason for this is that the semantics of regions are often independent or only loosely related to the semantics of the entities they contain or the actions that are performed within them. This makes it difficult to describe a user's location in terms of activities. For example, landmarks where a navigation decision should be made, a point of historical interest that can be viewed and learnt about, or simply places that different individuals found inspiring and important. A further reason is that the types of geographic relationships that can be described are poorly suited to the modes of thinking and behaviour employed for activities. Usually these are more action-oriented and narrative. For example, it is difficult to describe sequences of turns and paths for way-finding based on a regional model of location because it is very hard to formulate spatial relationships like "being next to", "in front of" or "between". Representing location in these place-based ways requires geographic referents that are more structural, spatial configurations that can be easily compared to the way in which the world is directly experienced. Hence, place-based models of location might be underpinned spatially, through a map, or non-spatially through a verbal or textual medium.

Because of these differences regional models of location can be thought of as constraining the relevance of information and place models as constraining activity relevance. Schlieder et al. (2001), however, suggest a region-based approach that also copes with activities. They structure regions hierarchically and relate different types of service (e.g. navigation, information retrieval) to different levels. They interpret activities by analysing the dynamics of a user's movement and use this to identify services relevant to a particular regional level. Their solution operates by extending the semantics of regions to consider the types of activities performed in them and therefore services that are relevant. Essentially regions are qualified in terms of activities. Describing them in this way brings them closer to the notion of places, since the region becomes a setting or modifier for activities rather than a container of things. The frame-of-reference is primarily between a type of service and an interpreted activity rather than between locations, which are secondary.

The goal of Schlieder et al. (2001) was to automate the presentation of services according to behaviour. This compares to the emphasis of (Reichenbacher, 2004, p.8) on location-based services that have low interactivity, instead interpreting of user's needs for information and service provision based on contextual cues. For the most part, WebPark services followed a more interactive model. Visitors would select the service relevant to their activity (e.g. navigation, observation, searching for facilities etc.), though the information provided by these could be adapted to their context, such as their location, time, personal interests and pattern of movement (Mountain, 2006).

These two approaches to interactivity can also be seen as the difference between push and pull service models. In the push model information is provided automatically to the users, i.e. it is pushed to them. In the pull model information is sought and accessed interactively, i.e. it is pulled down by the user. Location in pull services allows the user to create places themselves in a more-or-less *ad-hoc* fashion. They stop in places they find interesting and enhance their experiences through actions and information that supports these. In the push model, location triggers the creation of places that are predetermined or at least determined by the system. They focus attention to an activity that can be performed in a particular locale, for example by metaphorically saying "Stop and look here".

This underscores a further important difference between places and regions as models for location. Regions are representational frameworks for describing locations, in spite of the difficulties of defining their boundaries. Places, to an extent, are non-representational. They emerge out of the dynamics of activity, interaction and experience (Tamminen et al., 2004; Harrison and Dourish, 1996). If these places can then be communicated through convention, culture, or perceptual characteristics they can be solidified representationally.

6.5.1 Typology of Regions

The analysis of user's questions in Chapter 4, highlighted the different modes of thinking of users in seeking information and undertaking actions. Particularly in asking questions in the form "What x can be found in y?", and "Are there x in y" (Table 4.6), visitors employed a regional way of thinking about their location and the kinds of things that might occur there (see Figure 4.2). An issue evident was thus how to join the two types of information that could vary as x and y. That is, how to define the locations where entities could occur as semantically meaningful regions. Problems inherent in this issue have been touched on in Section 6.2.1, in relation to the mis-match between data sources that were spatio-temporal and those which were informative but aspatial. To tackle this issue the task described in Figure 6.2 as re-modelling, that is defining the location models, was applied.

The definition of regions could be made from one of three perspectives, that varied according to the subject whose semantics were being described. Regions could be defined based on a visitor and their location, according to the wildlife entities of interest, or independent of either. Figure 6.11 illustrates a typology of different types of regions that is suggested by these differences.

User-centred regions are ego-centric depending on aspects related to the user's

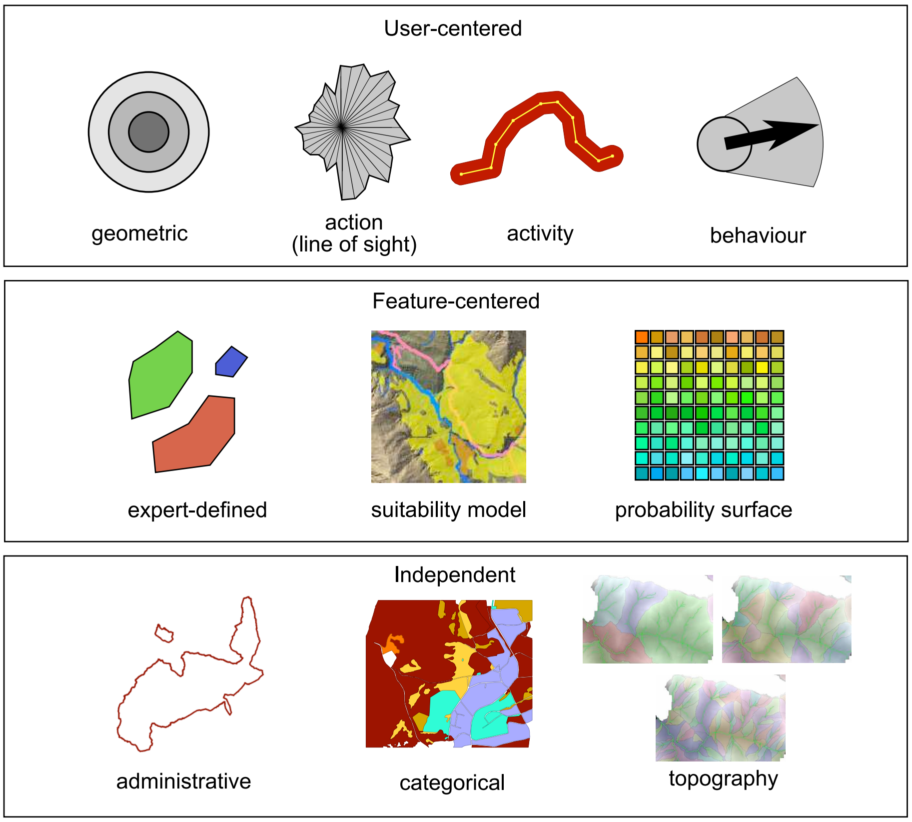


Figure 6.11: Typology of regions for locations

context for their definition. Geometric regions are those generated by associating a visitor's location with a function such as distance. For the most part, these are the same as for location based on positions. Action regions describe regions related to visitors' actions such as observing. An example of this might be the region visible from a position computed with a viewshed (Llobera, 2003). An activity region is a space that will be navigated during a user's activity, for example the path they will walk along. Behaviour regions use aspects of the user's behaviour, e.g. space, time and heading, to describe a region of geographic relevance (Mountain, 2006; Brimicombe and Li, 2006).

Feature-centred regions are defined by feature semantics. They seek to describe spaces in terms of some aspect of the behaviour and life-cycle of the entities, for example where they live, their territorial ranges or simply where they are known to be found. Expert defined regions are placed manually by consultation with a wildlife expert or park administrator. Suitability models generate regions of habitat preference for different species. Probability surfaces use data from known observations to generate density surfaces describing likely occurrence.

Independent regions have no default relationship with the a particular individual or entity, though many will correlate to some aspect of a user's activities or a entity's occurrence. The most obvious example of an independent region is the boundary of a park or protected area. Such regions are usually defined legally and administratively and as such have *fiat* boundaries (Smith, 2001). Mainly they have little semantic relationship with the entities of interest or the visitor's actions, but provide useful cognitive frames-of-reference for scoping information to well-known names of places. Categorical regions also have fiat boundaries though frequently they will coincide with *bona-fide* (Smith, 2001) ones. They are defined using classification schemes and empirical measurements and include types of properties such as vegetation, soil, forest cover, land-cover and eco-types. Whilst the semantics of such regions are independent they will often correlate to habitation aspects of wildlife entities, for example certain plants will only be found on certain soils or vegetation units. Topographic regions generally have bona fide boundaries formed by distinct breaks in the earths surface (Smith and Varzi, 1997). As such they may correlate with aspects of a visitor's activity or the behaviour of wildlife. An example are the network of ridges and catchments found in mountainous areas (Burghardt et al., 2004). These impinge on both the space that is accessible to a visitor and where they can see, as well as produce natural boundaries to aspects of animal behaviour.

Regions can be easily combined to better account for locational aspects related to both the visitor and the entities. For example, insects can only be viewed over short distances, so it makes sense to limit the location model of insects by those regions over which the action of viewing them can take place - for example with a geometric region defined over a short distance.

6.5.2 Regions for Wildlife Information in WebPark

The principal reason for employing regions as a locational model in WebPark was to allow the user to search for information around their position. Regions provided spatial indexing schemes that were sensitive to the geography of visitors locations and semantics and geographical distribution of the features that were indexed. Different types of region were employed based on the type of entity and to some extent the available data.

Re-modelling birds

In the SNP regions of habitat suitability for song birds were available (Filli et al., 2000). This ranked suitability on a scale of zero (unsuitable) to three (best suited). Figure 6.12 shows the habitat suitability for Chaffinches (*Fringilla coeleps*) in the SNP.

Because the distance over which birds could be observed by visitors was limited to around the immediate area around a path, this information was then limited to encompass only these areas. The process of preparing the data in this way is called re-modelling in the terminology of Figure 6.2. Figure 6.13 illustrates the process.

The remodelling consisted of two stages. In the first, the spatial data for the habitat suitability regions was intersected with regions based on the paths. This

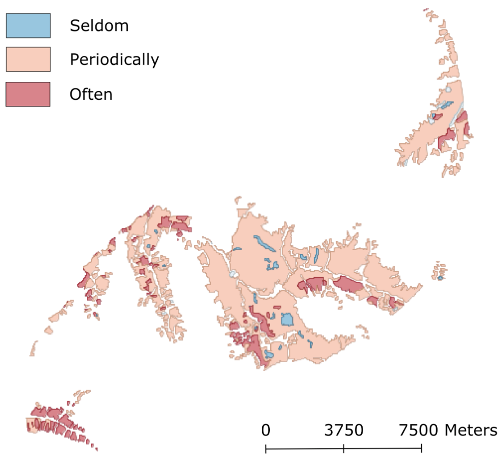


Figure 6.12: Habitat Suitability Model for Chaffinch (Filli et al., 2000)

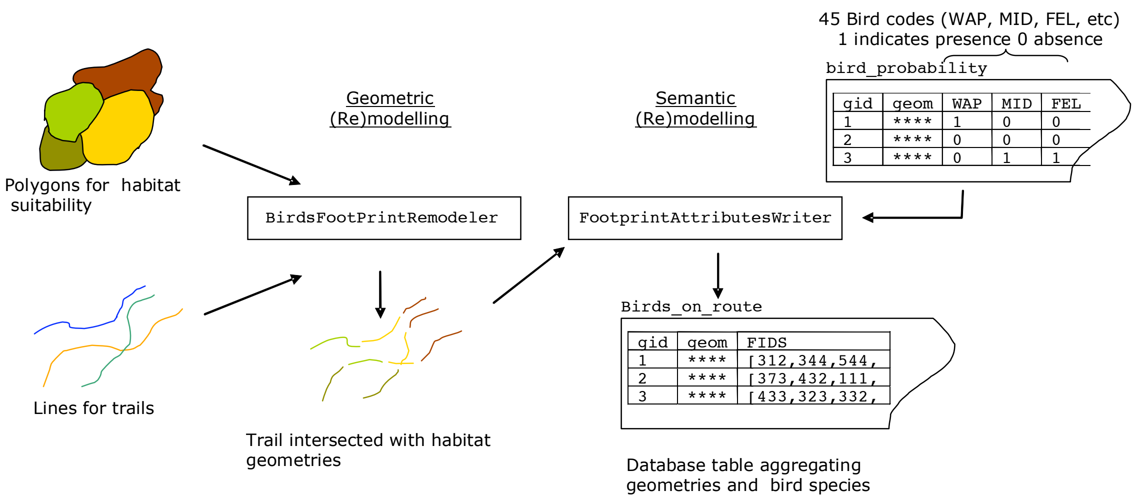


Figure 6.13: Re-modelling process for songbirds in the SNP

was performed in Java using the class BirdsFootprintRemodeler. The second stage associated the occurrence of the different birds with the regions. This process was performed by the class FootprintAttributesWriter. It added the feature identifiers for a bird to the regions where it could be found, modelling a many-to-many relationship between bird categories and regions.

In the second study area, Texel, locational data for birds was much more limited. The best that was available were descriptions of preferred habitats in terms of land cover types. For example “Beaches, rock coasts and sea cliffs” and “Mud flats and salt marshes”. These descriptions were then mapped to land cover units available for the island to create a loose definition for habitat preference.

Re-modelling Ungulates

Ungulate data (i.e. red and roe deer, ibex, and chamois) mainly consisted of point observations. To remodel this, regions approximating visibility based on the topography were constructed. This involved computing the drainage morphology for stream channels at different stream orders (Burrough and McDonnell, 1998). The resulting hierarchy of regions gave an approximation of the area visible from a point at different scales. Figure 6.14 illustrates this process.

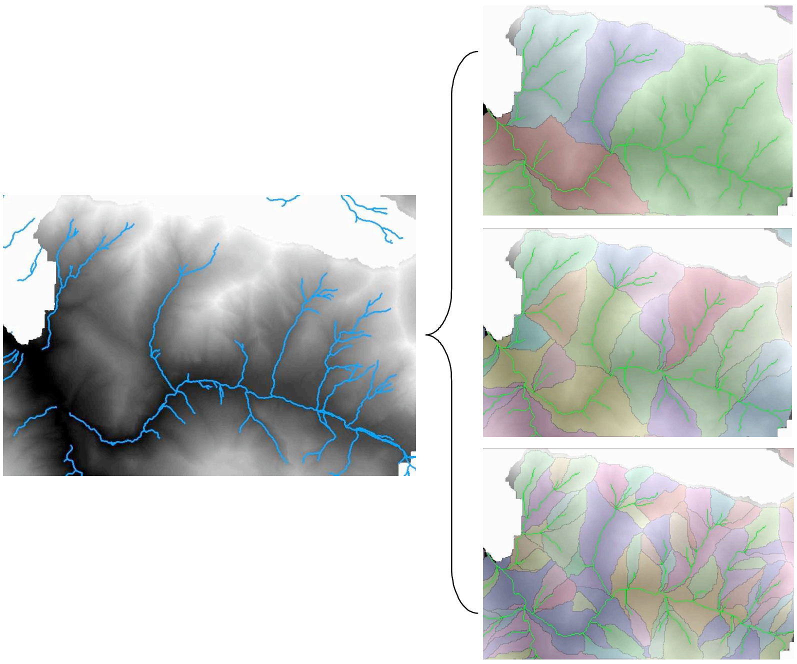


Figure 6.14: Re-modelling process for ungulates (Burghardt et al., 2004). Hierarchies of regions (right) are generated from the calculation of catchments for a DTM (left) for different stream orders

Because visibility is also strongly influenced by the land cover, forested regions were intersected with the produced catchments. Figure 6.15, shows the cover of visibility regions for the SNP. An alternative approach might have been to calcu-

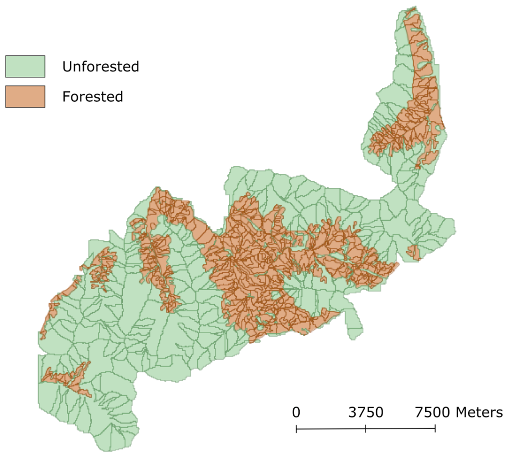


Figure 6.15: Visibility regions, partition of catchments classified according to forestation

late viewsheds from each observation point and combine these within a probability surface. The main reason for not pursuing this approach was that to be useful a surface would have need to be generated for each ungulate species. This would then have required the mobile client device to hold and process much greater volumes of data.

Re-modelling Rare Species and Wildlife Places

Some data was less suited for re-modelling using location regions. This was because it was either highly heterogeneous, making a choice of semantically appropriate regions very difficult, or because wildlife was already strongly tied to a specific location.

An example of the former type was a dataset of rare and significant plants and animals available for the SNP. This consisted of observations made by rangers during the course of their day to day activities in the park. The variety of plants and animals was very wide and in addition the frequency of sighting for different species was highly variable both in absolute counts and over time. Rather than attempt to associate this data with any specific model of locations it was instead kept as spatio-temporal points.

An example of the second type was data, both for Texel and the SNP that was defined by expert knowledge. This consisted of points and areas describing places that were known to encompass specific species. This type of data therefore brought the action of observation close to the definition of the location of the species.

6.5.3 Indexing Location

An aspect highlighted by the work of Schlieder et al. (2001) is the need to identify dynamically which locations, for example from a covering of regions, are relevant to a user at a particular time. They term this problem *disambiguation* and suggest a solution by interpreting the movement pattern of the user. In Heidmann and Hermann (2003),Edwardes et al. (2003b), and Reichenbacher (2004), the problem is described in terms of the spatial scope or range of an activity or context. When location is defined geometrically scope and location can be viewed as the same. They are determined dynamically in a continuous manner, using distance ranges from a particular position. This was illustrated previously in Figure 2.2 in terms of scale. Locations based on regions, however, are discrete and are systems of organisation that are only loosely related to scale. The problem is then how to add a dynamic component using the scope.

The problem can be dealt with in a number of ways as illustrated in Figure 6.16. The figure shows three techniques to deal with scope. It can be ignored and only the

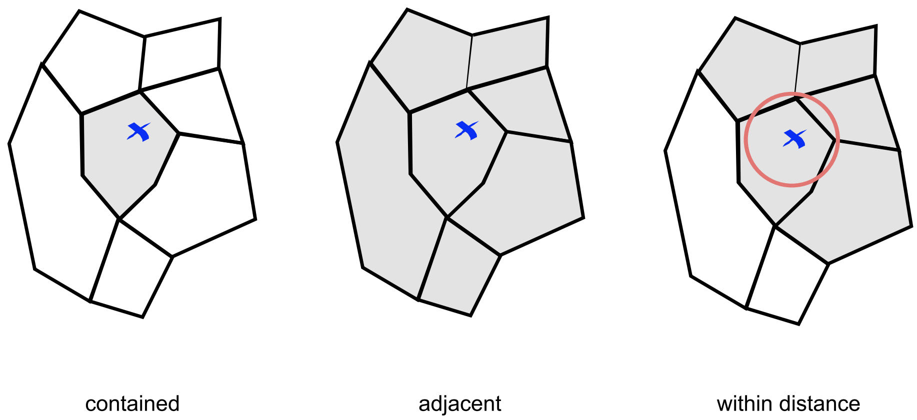


Figure 6.16: Dynamically identifying locations with spatial scope

region that contains the current position examined. However, if a person is close to the edge of a location region the information retrieved solely for the region may be less and less useful. It can be handled topologically, by looking in regions that are adjacent to the containing one, or within the same parent region of a hierarchy. The problem here is that depending on the shape of the region this might retrieve too much information that is relevant to distant locations. Finally, it can be approached geometrically by selecting the regions within a distance of the position. Whilst this limits the scope more locally, it introduces many of the potential problems of geometric defined regions, such as their ignorance of the geographic fabric of the space being explored.

A further problem is how to determine the extent of the scope. In a purely (geo)metric solution between a visitor's position and observation points, a distance range needs to be defined. Likewise, when a geometric scope is used to limit regions.

In a topological solution n-order neighbours can be used to create different subsets. The issue of defining the extent of the scope is closely tied to the activities being performed. Different kinds of actions will take place over different ranges and hence require different location scopes to limit or extend the amount of information that is of interest. For example, planning where to go in a park involves a consideration of information for a wide region, whereas looking for animals to observe from a viewpoint requires a much more limited scope. Particularly for activities over larger scales, scope therefore becomes increasingly understood in terms of semantics and so itself becomes a type of region or place. For example the whole park or a path within it.

In WebPark three levels of scope were defined. For very localised actions the scope was determined geometrically by considering all the regions within a distance of the user's position ("Search around me"). To limit information relevant to the execution of an activity, a region based on the path being followed was employed ("Search along path"), and for planning the region of the whole park was used ("Search the whole park").

6.6 Information Modelling

The aim of location modelling was to answer questions phrased in Table 4.6 of Chapter 4 – "What x can be found in y?", and "Are there x in y". Information modelling moves the attention to the remaining three forms of question "What x is this?", "Is this an x?", and "Where can x be found?". These types of question seek to enquire about the identity and characteristics of entities and so represent a path into the service primarily through semantics rather than location. In WebPark, the information model needed to organise information related directly to the description of a wildlife type (see Figure 6.1).

The modelling of information in this way entails three considerations:

1. How should feature type (species) categories be organised so that the semantics of a classification will provide a route into the information?

2. How should knowledge links defining relationships amongst feature types be managed?

3. What information is required to describe a feature type and how should different forms of information be coordinated?

6.6.1 Taxonomy

The main point of entry to exploring descriptive information about wildlife entities is through their names and the categories in which these are collected. Such a classification can be organised in different forms, for example as a tree of child and parent classes, or a semantic network. A conceptualisation of entities in this way can be described as an ontology (Agarwal, 2005). In WebPark the term ontology was applied in a fairly simple sense. It equated conceptualisation with object identification (Schuurman, 2005; Raper and Livingstone, 1995) and the creation of tree-type taxonomies, rather than a more rigorous and formal system of description logic for knowledge sharing through explicit semantics (Gruber, 1995; Guarino and Giaretta, 1995). Modelling knowledge was instead created through inter-linking information based on entity names inside the information framework described later in Section 6.6.2.

As illustrated in Section 4.5.3, taxonomies are closely related to their end purpose of use. For instance, for someone interested in reviewing general information about birds a broad taxonomy based on the Linnaeus classification might be most appropriate. If their interest is in finding out about birds common to a particular place, a taxonomy based on habitats or basic levels (Rosch, 1978) might be more useful. A taxonomy of birds for identification could instead be organised according to the characteristics of the 'general impression of size and shape' (giss) of a bird. Figure 6.17 shows how it could even be visual. In this sense, a taxonomy

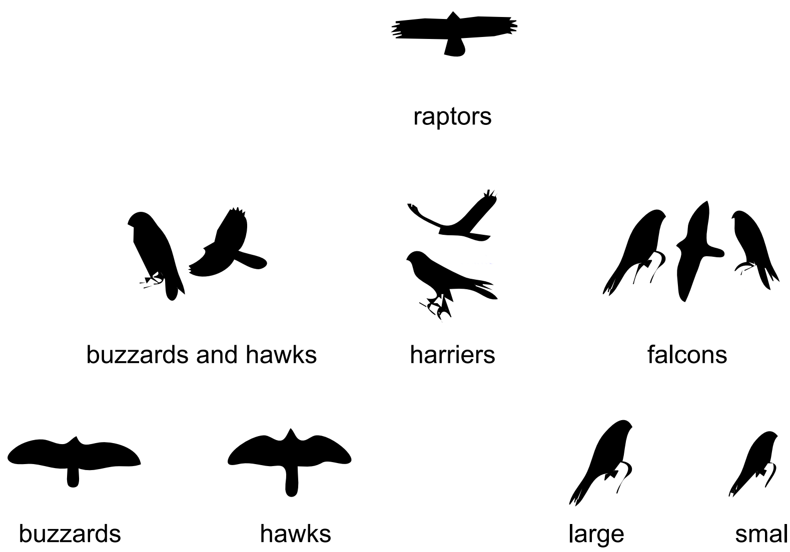


Figure 6.17: Example of a visual taxonomy for bird identification (graphics derived from ETI (2003))

is more of a method to style information for different purposes than a method for structuring data, since this would limit the application of the data model. For that reason, names within taxonomies were separated into *leaf* categories which were used to identify entities in the database and parent or *node* categories which were dealt with as part of the presentation of the application. In some cases information relating to leaf categories needed to be recategorised, using an ontological mapping, so that for example information about "Bearded Vultures" and information about "Bartgeier" (German) were considered to relate to the same feature type.

6.6.2 Information Organisation

The entity types also provided the focus to draw both descriptive and locational information around a common data unit. Different types of descriptive information were associated with a feature. These are itemised in Table 6.3. Most of this

Media	Examples
Text	Hyper-linked textual descriptions about plants and animals, their life-cycles, behaviour and inter-relationships.
Images	Photographs of plants and animals in their natural habitats
	Illustrations of birds drawn to support identification
Maps	Density surfaces based on ungulate observations
	Choropleth maps showing ungulate distributions
	Habitat suitability maps for songbirds
	Maps showing recent observations for various plants and animals
Sounds	Bird calls
Movies	Short films of animal and bird behaviour

Table 6.3: Types of descriptive media associated with a wildlife type

information was obtained from the CD-ROMs described in Table 6.1. Whilst sounds and movies were available for the SNP, these were not used for fear of disturbing the wildlife. The information was stored on the server and content management system as previously described. On the device it was encapsulated in the IFOI model using, so called, 'native-content' links to appropriate multimedia files. XML Xpath links were used to relate feature types to other feature types and to locations. Thus, for example, on querying for "What is near me?", a visitor might be informed that golden eagles and marmots were often seen in this area. On clicking on information about marmots, point locations of individual marmot sightings could be displayed. Associated with these marmot sightings might be multimedia describing marmots, and since golden eagles predate on marmots a link to the golden eagle entity. Using this model it was possible to have entities that were: 1) non-geographic but still available via the system (e.g. general rules of the park, history); 2) semi-geographic being spatially indexed to locations according to expert knowledge but having no mappable distributions; and 3) geographic being both locatable and mapped. Figure 6.18 illustrates the complete model.

6.7 Modelling Spatial Information

Mapping requirements for WebPark took two forms; real-time dynamic maps and static descriptive ones. Point-of-interest maps, produced in response to users ad

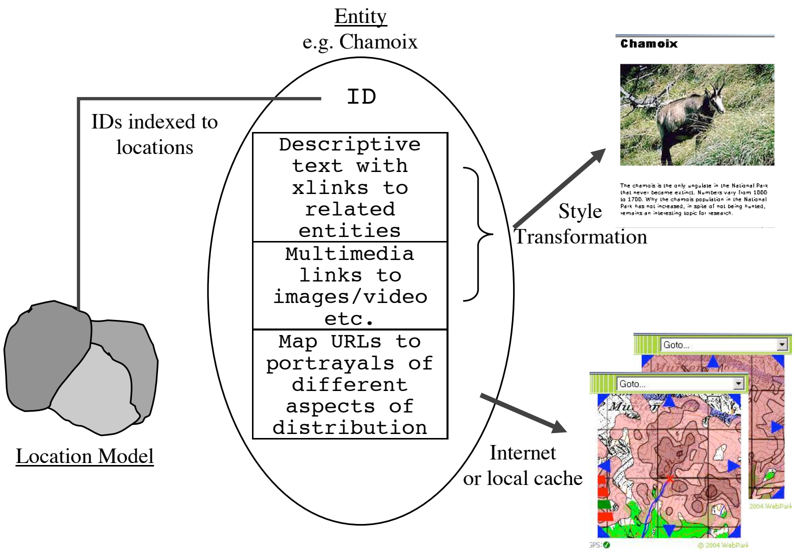


Figure 6.18: Design of the model for information provision

hoc queries were examples of the first kind. This type of map is discussed in more detail in Chapter 8. Here, the latter type will be considered. Examples of these are thematic maps showing spatial distributions of a species. These types of map represent a geographic perspective that is strongly spatial. They present spatially varying patterns, distributions and densities aggregated over relatively long time scales and so are largely independent of the the map viewers location and the time the map is being viewed.

6.7.1 Data Handling

Because the spatial representation were largely independent of a visitor's context, being compiled from data over a relatively long time scale and for broad areas they could be pre-computed and cached and then associated with the features as a form of multimedia content.

A number of data processing operations needed to be performed to support the production of these more static thematic maps. This involved the steps:

1. Modelling the desired representations (e.g cluster map, density surface)

2. Generalising the data to minimise data volume for different scales and (re)modelling it in multi-resolution database tables

3. Implementing data accessing logic (SQL statements) using the tables of step 2 and generating map data in the form defined in step 1

4. Integrating the access logic within a map specification to be used by a web map service.

5. Updating the database with metadata about the maps

Step 1 is a mainly manual design process. It involved the definitions of map types; point observation maps, proportional point maps showing observation clusters, choropleth maps, and density surfaces. For each type of map a definition of classes of information and their boundaries then need to be defined. In addition scale relevance was identified. Finally the styling need to be described, for example what icons would be used. This information was translated into map styling definitions.

The next step was to prepare the data for the maps. Generalisation took two main forms; simplification and amalgamation (McMaster and Shea, 1992). Simplification was performed on the linework of polygonal coverages. This largely used commercial GIS packages (e.g. ArcGIS and FME), but an implementation was also made in Java that could simplify polygonal data stored in the database, using the line simplification algorithm of Visvalingam and Whyatt (1993), whilst ensuring topological consistency was maintained (no self-intersections or intersections with other features were created). This was largely based on the work of Yang (2005). Point set simplification was also performed to reduce the number observations whilst maintaining an impression of their distribution. This used clustering to allocate points into groups and then represented these groups with their centroid (Burghardt et al., 2004). Amalgamation was performed using ArcGIS on polygonal coverages. It dissolved boundaries between polygons that had been (re)classified with the same attribute. Habitat suitability maps for birds are one example where this was performed. Here the dataset first had to be disaggregated for each bird and then the polygons related to a single bird amalgamated. This created a unique dataset for each bird which was then simplified and imported into the database. Density surfaces might be described as another form of amalgamation for points. These were derived from animal observation data.

The third step was to define SQL statements to extract the data from the database and group it into the classes defined in Step 1. Oracle provides a number of functions to aggregate data which were used for this purpose (see Lorentz and Gregoire, 2002, p.6-8). These functions were used for generating class aggregations for choropleth and proportional point maps. The final step was to generate a map definition file that integrated the map design styling with the data layers. This used the format of the Geodan web map server which is based on the Prolog programming language.

Having defined the maps that were to be delivered, the final task was to store this information as metadata in the database. The purpose of this was:

- to support the centralised management of maps
- to allow maps to be described as multimedia type content in the feature definition of the application logical model, and
- to allow map requests to be automated in the processes of harvesting by separating the maps into tiles.

Figure 6.19 describes the tables used for managing maps. The central table is

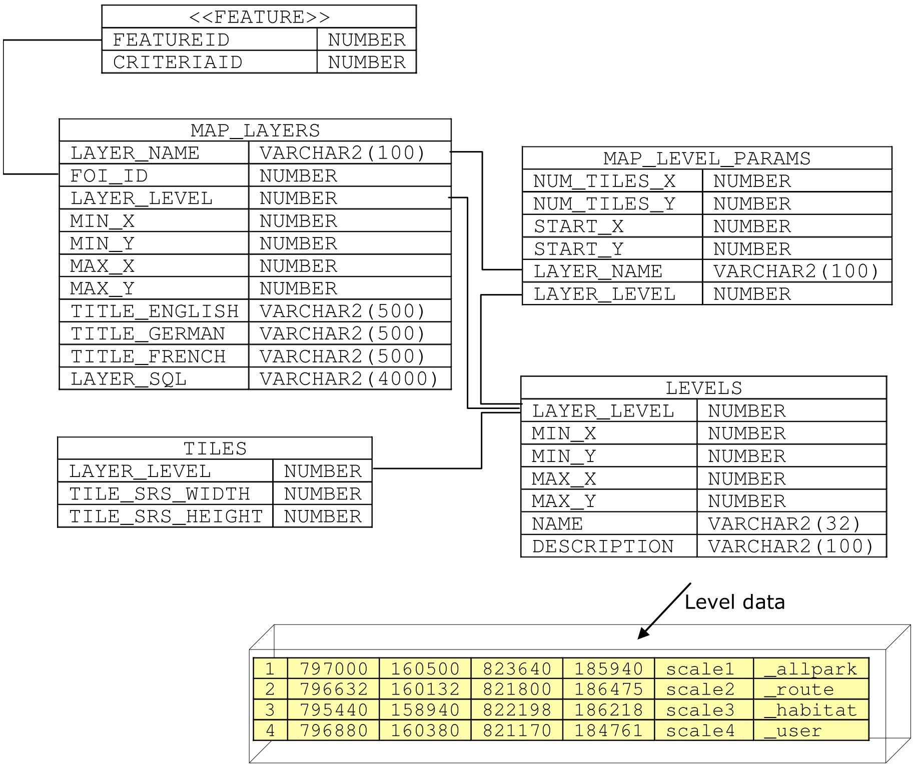
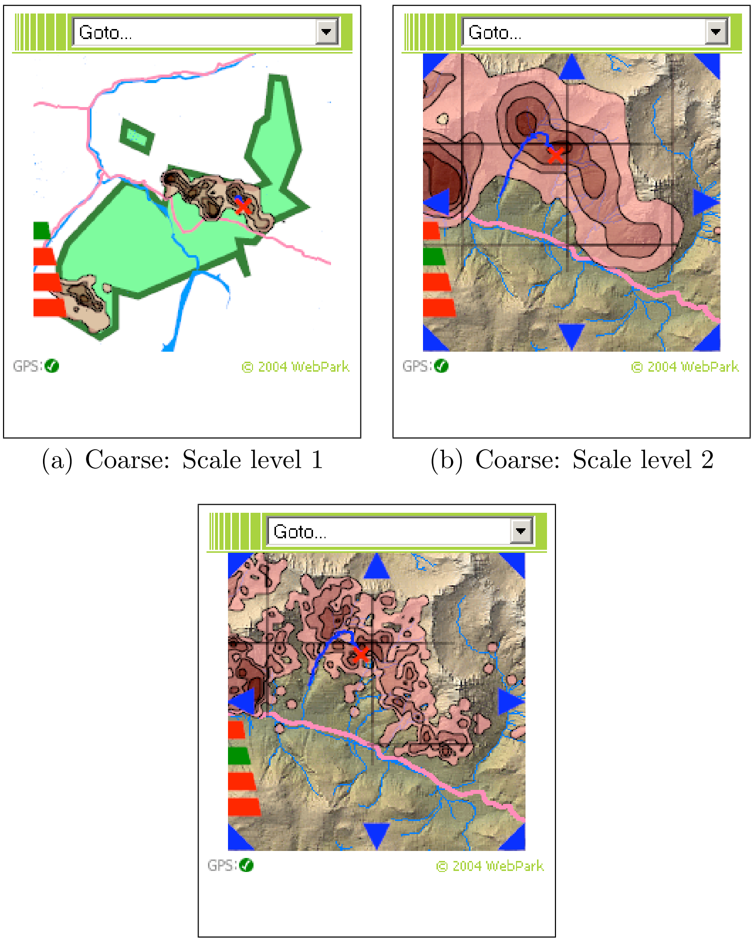


Figure 6.19: Tables used for structuring metadata about thematic maps

map_layers, this relates the maps defined in the previous steps to features in the database. It stores information on the map extents, the map scale, the map title and the SQL statement used to generate the map data. The map scale is organised into a set of four levels described in the levels table (the contents of this table are also shown). The actual scale is determined using the extents defined here and the resolution parameters defined in the tiles table. Hence each named map may have up to four entries in the map_layers table, one for each level. The table map_level_params provides data on the number of tiles that a map at a particular layer can be broken up into for a given level. These tables can be used to automated the creation of the mdf files. A critical use of these tables was to generate map request strings for each tile that could be requested by an application. These strings were stored on the feature data, discussed next, as a form of multimedia. This joined the two types of web service (mapping and data provision).

6.7.2 Map Examples

Figure 6.20 shows examples of density surfaces produced from observation data about ungulates. The surfaces were generated at different resolutions which allowed them to be presented more effectively at different map scales.



(a) Coarse: Scale level 1

(b) Coarse: Scale level 2

(c) Detailed: Scale level 2

Figure 6.20: Density surfaces based on observations of groups of chamois. Two different kernel sizes are used for computing the surfaces, allowing for generalisation of details at the smaller map scales.

Figure 6.21 illustrates a choropleth map based on ungulate observation data. Here the data has been aggregated to vegetation units, in a manner similar to that described previously in Section 6.5.2. Other units, such as the catchment could have also been used. The main issue with these maps was that the units were often too large to present the distribution of the animals and their relationships with the environment in a faithful manner.

In Figure 6.22, examples of the habitat preference maps for songbirds are presented. These present the likely occurrence of a song bird based on models of habitat suitability developed by the SNP and derived largely from the park geology (Filli et al., 2000). These could have a range of four possible classes, seldom, periodic, often and very often (selten, regelmässig, häufig, sehr häufig). Though typically only the first two were used.

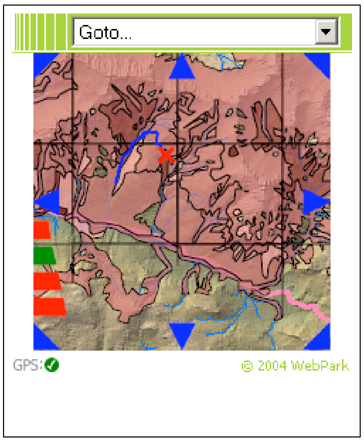
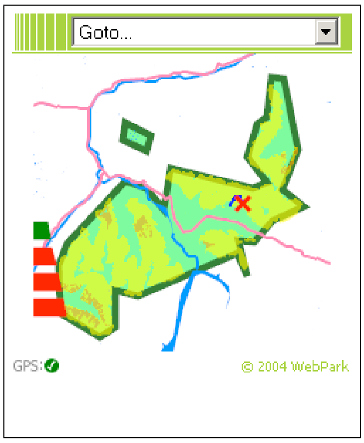
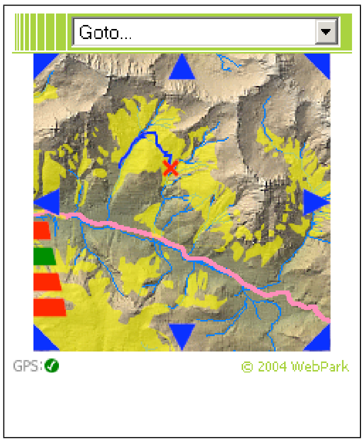


Figure 6.21: Choropleth map showing average number of chamois in a group by vegetation unit.



(a) Map scale 1

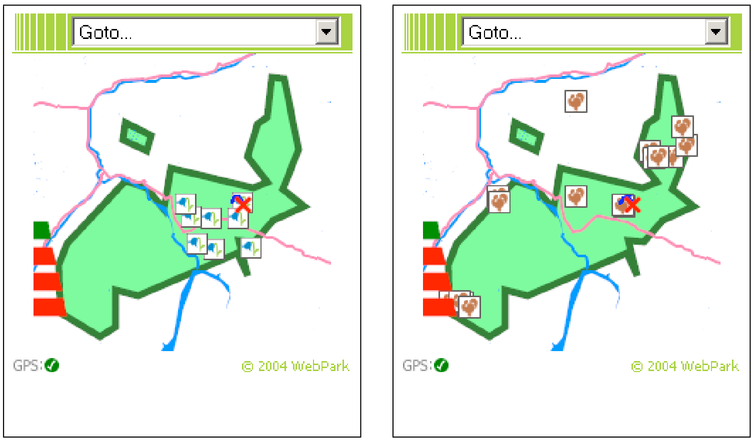


(b) Map scale 2

Figure 6.22: Maps showing habitats preferred by a Citril finch.

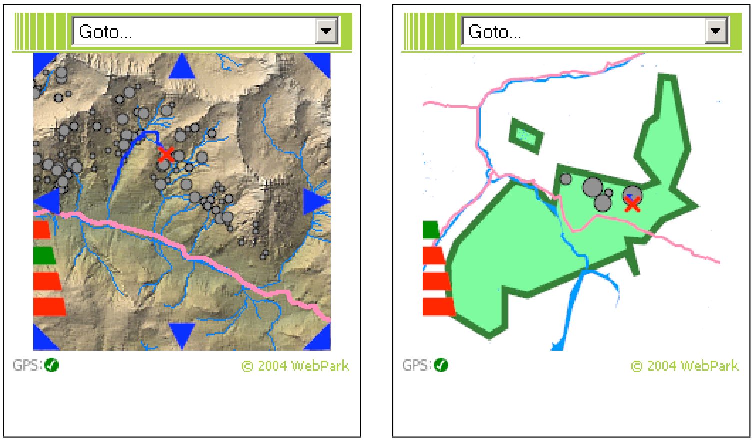
Figure 6.23 presents examples of recent observations of rare plants and animals. The number of points shown was based on the most recent twenty observations within a set time period from. The main problem here was that for some species recorded observations were highly intermittent meaning that in some maps very few points would be shown.

Figure 6.24 illustrates examples of proportional point maps based on ungulate observation data. The grey colour of the points is due to a failure of the desktop application being used, in the application these were usually shown in red. The maps shown have changed the size of the points according to the number of animals in a recorded group (left) and the number of recorded groups within a cluster (right).



(a) Bellflowers (b) Grouse

Figure 6.23: Maps showing recent observations for a plant and an animal species.



(a) Number of animal observed in a group (b) Clusters of observations

Figure 6.24: Proportional point maps based on data about observations of groups of chamois.

Chapter 7

Controller: User Interaction and Application Design

In this Chapter the issues for application design raised in the analysis of questions (Chapter 4) will be considered in terms of how the interaction with WebPark application for flora and faunas was implemented. Conventionally in software engineering the controller implements the logic of an application which is usually executed in response to some form of interaction. This functionality is accessed through different visual controls which are called views. However, here the controller is taken to refer to both the types of interaction facilitated by the application and the visual component used to allow this. The view, discussed in the next chapter, is taken to mean the map interface and independent processes that allow it to operate dynamically with respect to its internal requirements for presenting spatial information effectively. The discussion here will focus on the interaction paradigms and dialogues of the flora and fauna application. Whilst much of the conceptualisation of the controller was the authors own, the implementation was largely performed by other members of the WebPark consortium.

To consider the different forms of control employed, the typology of 4.2 again considered. There four conceptual domains were categorised; kinds, descriptions, percepts and locations. How these were implemented in the application has largely been described previously in Chapter 6. These concepts were linked by sets of different actions: verify, identify, observe, situate, locate, occur, and inform. These actions relate most directly to the issues of interface design and so are considered here.

7.1 Portal Interfaces

Figure 7.1 shows the main interfaces through which the applications were accessed. These were used by both the flora and fauna application and all others. The graphics are taken as screen grabs from a version of WebPark that runs on a desktop PC. The WebPark homepage, shown in the centre, provided three points of entry via

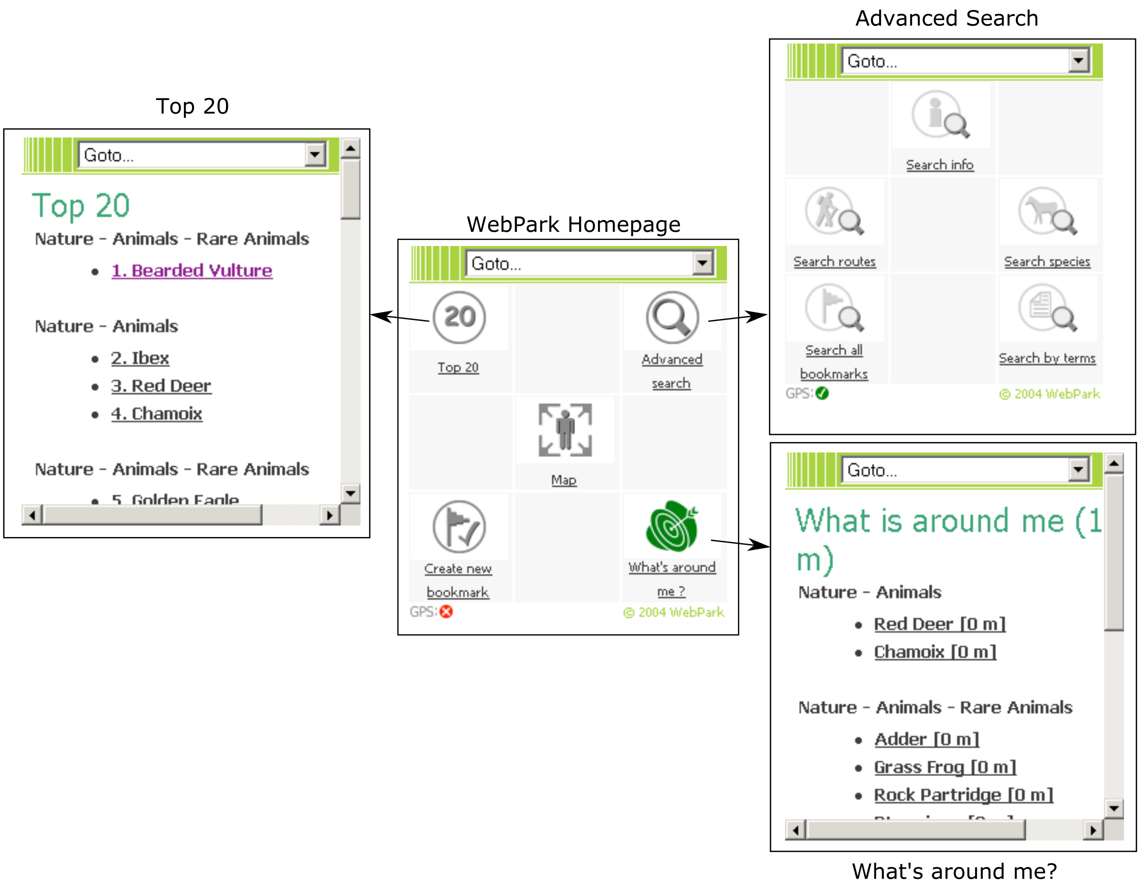


Figure 7.1: Entry screens for the WebPark portal relevant to the flora and fauna application.

hyperlinked icons. Top 20 presented the top twenty items of interest based on the knowledge of the park management. For the flora and fauna, this essentially listed kinds from the perspective of the *basic levels* discussed previously in Section 4.5.3. The advanced search allows the visitor to employ different mechanisms for searching for the information according to how it is organised in a taxonomy (see Section 6.6.1). The "What's around me icon?" searches the information according to spatial constraints based on the regional characteristics of the information and the visitor's location (see Section 6.5.3). Ultimately each provides access to the same information model, the departure being that they allow different forms of constraint to be applied in interrogating the model and hence different types of action to be enabled.

7.2 Information Presentation

Figure 7.2 shows interfaces visualising the information model for the kind and description of 'Bearded Vulture', as accessed through the Top 20 interface. The in-

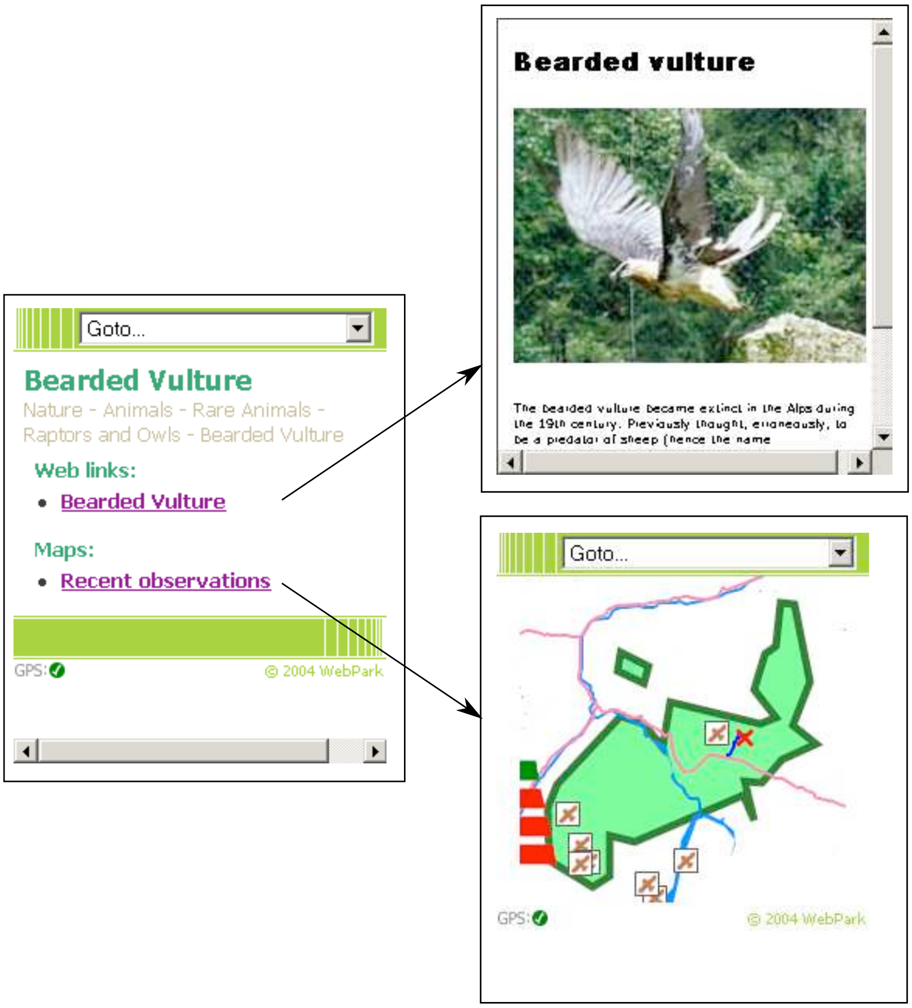


Figure 7.2: WebPark application interfaces to access the information model of a bearded vulture.

terface on the left in Figure 7.2 organises the information model into semantic descriptive information and spatial information, allowing the visitor to perform the actions of inform and locate respectively. Since the descriptive information is a web page, knowledge relating species, e.g. predator-prey, can be structured using hyperlinks. The red cross with a blue tail on the map represents the visitor's position and their recent navigation history allowing them to better orientate themselves with the information about observations.

7.3 Locating Information

Figure 7.3 shows dialogues from interaction with the "What's around me?" function. The function allows the visitor to search for all kinds in the information model related

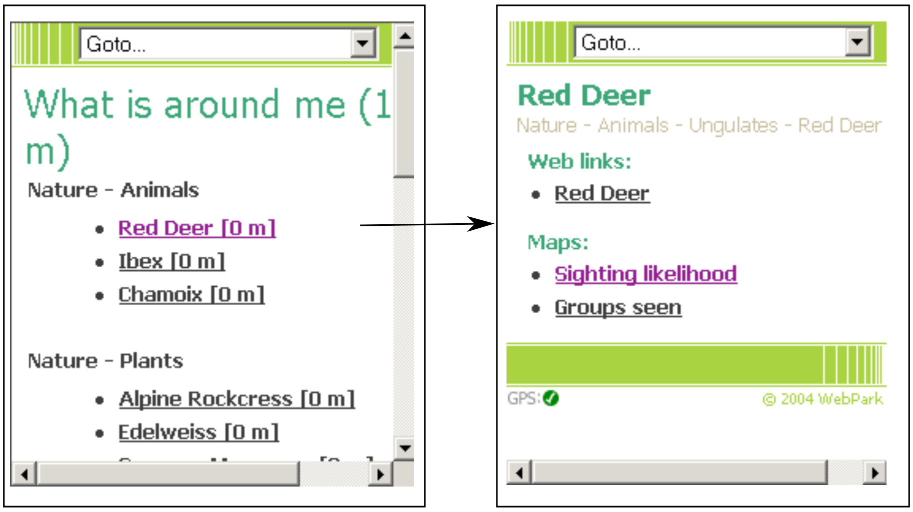


Figure 7.3: WebPark application interface to query the information model according to a visitor's current location.

to their position and as such it affords the user the actions of occur and observe depending on the type of spatial information that is available. The function uses the different models of location described in 6.5 to determine the spatial relevance of various types of entity to the visitors position.

7.4 Advanced Search

The dialogues for the advanced species search are shown in Figure 7.4. The interfaces uses a drill-down form of dialogue allowing the visitor to select flora and fauna at different levels of granularity in the taxonomy (see 4.5.3). Having selected the species they are interested in the 'View as List' hyper-link lists the selected items in a similar way to that shown in Figure 7.3. Different spatial constraints can be set on the search producing slightly different visualisations. If the option of searching in the whole park is selected all entries in the information model can be queried. This effectively deals with the actions of verify where the user wants to review different types of entity without constraint. The other option is to search around their own location. This uses the model of regions described in Section 6.5 to relate the visitors position to the occurrence of different types of flora and fauna. This option affords the visitor with the actions, occur and observe. When a species can be found nearby a tick is shown next to the name and when it can't the entry is greyed out, as shown here for 'Roe Deer'. The action of identify is also implemented here to an extent, for example taxonomic descriptions for some song birds are based on their general impression, such as their relative size or colouring. However, this is fairly limited since the visitor would need some knowledge of birds. Experimental interfaces were explored using silhouettes of birds such as those illustrated previously in 6.17 but

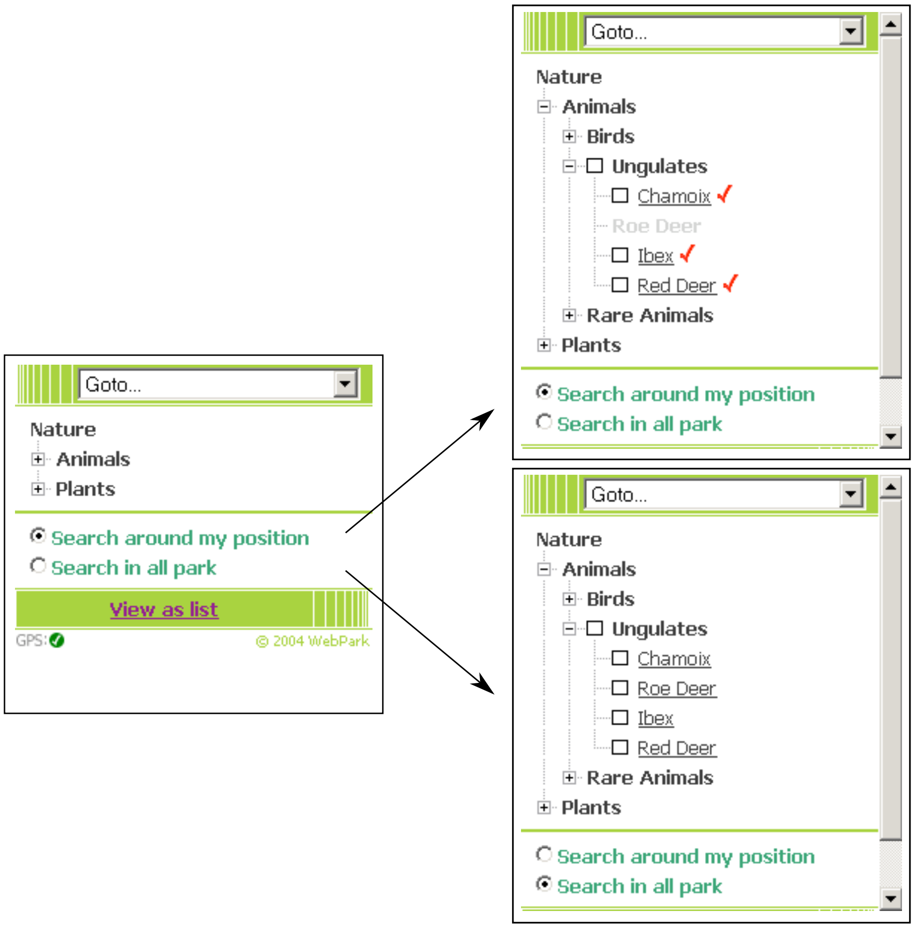


Figure 7.4: Interfaces for advanced species search under different spatial constraints.

these were not implemented in the final version. Interfaces for identifying plants starting from the colour of their flowers were also implemented by the company who deployed the WebPark application subsequent to the project.

Chapter 8

View: Portrayal and Graphical Organisation

8.1 Introduction

The role of the view within the presented MVC architecture is to manage the presentation of information on the device. A view is manifest for every interface within an LBS, however here the focus will be on the view as a map-based interface for organising spatial data. To an extent how such data is visualised has been discussed in Chapter 6, in the discussion of maps to show spatial distributions of phenomena. The reason for describing those data there was because they are relatively static representations and therefore more closely related to a form of descriptive multimedia. Here instead the task of visualising information that is produced dynamically in response to user interactions, for example by searches and changes in context, will be considered.

This type of information is termed foreground information in the discussion. The dynamic display and conflation of foreground data constitutes the key difference between information resources that are products, like paper maps, and the service orientated provision that is demanded by LBS (see 3.3). This is because the maps produced are highly ephemeral and particular to the needs of single individuals. They are compiled at the moment they are requested and so any cartographic issues dealing with their presentation cannot be dealt with until the moment they are produced. This means that the view must be furnished with the ability to act independently to ensure the map is usable. Further, when a map is requested in LBS is usually related to the needs of a particular situation. Hence, the presentation of the information should try to integrate characteristics of a users context, such as their location.

8.1.1 Portrayal

This description of the view as an independent component controlling the display of information according to the particular characteristics of how it is being used, brings it close to the idea in GIS of *portrayal*. The International Organization for Standardization defines portrayal as "presentation of information for humans" (ISO-19117, 2002, p.3). The vagueness of this definition is representative of the abstractness of the concept in general. It is however made more concrete in ISO-19117 (2002) through the definition of an abstract schema for describing the portrayal of geographic information largely through methods for styling geographic features. Whilst they note that, "Portrayal shall not be limited to visual rendering, but may include audio, tactile and other media" (p.9), the standard is most closely related to tasks of symbolisation. However portrayal of geographic information can also be considered to be concerned with a number of other techniques for presenting information that enhance one or more aspects of a map (Berendt et al., 1998) to bring the way in which it communicates closer to how the world is abstracted by a map user in particular circumstances (Klippel et al., 2005). These properties include;

- the geometric properties of the map projection,
- the topological relationships amongst the collection of geographic features,
- the level of detail used to describe features at different scales, and
- the media of the map (e.g. visual, audio, and tactile).

Various methods have been proposed to affect these properties, providing a broader context for the model of the view as a component of dynamic portrayal. *Schematic maps* enhance the presentation of topological information by relaxing the more geometrical properties of a map. This is especially useful in situations where essential information needs to be communicated rapidly because of the nature of activities it is required to support. Such a situation is typical in LBS where interactions with a mobile device are usually short but frequent (Ostrem, 2003). Some examples of algorithms implementing this operation include Avelar (2002), Ware et al. (2006), and Cabello et al. (2005).

Progressive vector transmission (c.f. Yang (2005), Bertolotto and Egenhofer (2001), Buttenfield (2002), and Brenner and Sester (2004)) dynamically adapts the level of detail at which features are shown to the scale of presentation. In LBS this is important because it allows high volume datasets to be accessed over networks with low bandwidth and because reduces the amount of data that needs to be rendered on a device with a small screen and limited computation capacity. Other methods such as clustering of foreground points-of-interest (Burghardt et al., 2004) are also aimed at dynamically adapting levels of detail for similar reasons.

Portrayal of geographic information using non-visual media is particularly important in LBS for situations where the user's attention must be focused on something other than a map, a classic example would be a car driver (Streeter et al., 1985).

The task here is to dynamically translate spatial data into natural language routing instructions, c.f. Rüetschi et al. (2006) and Tom and Denis (2003).

The main concern here will be on exploiting the geometric properties of the map through dynamic non-linear projections. In other work such techniques have been used to generate *detail-in-context* views of geographic information where the scale of the map is varied across the display from a central point of focus, c.f. Keahey (1997) and Harrie et al. (2002). Here, it will be used to re-organise overlapping map features.

What is interesting to note is that such approaches are not merely different ways of abstracting space but can also be seen as embodying the different types of geographic perspectives outlined in Chapter 2. Topological and portrayal using natural language media are often closer to the narrative based representations that are inherent when describing of places. Geometric and level of detail approaches exploit the spatial underpinning of systems of portrayal but do so to enhance the semantics of the information by highlighting salient characteristics and areas of interest.

8.1.2 Design Considerations

A number of difficulties are encountered in the dynamic presentation of information. The foremost is that when information is symbolised it can overlap with other symbols making the map appear cluttered and the individual signs unreadable. This problem is often exacerbated in LBS because screens are low resolution and therefore if the symbol itself contains much detail it needs to be shown larger than it would be on a paper map or high resolution screen. In addition, since symbols need to be hyper-linked to descriptive information, if they overlap it is difficult to maintain this reference and hence the ability of maps to be interactive (Chittaro, 2006).

The issue of conflicting symbolisation is well known in cartographic generalisation where the scale of a map is disproportionate to the symbolisation. Here the solution to improve the map is by removing data points, displacing them or replacing them with more abstracted concepts. In LBS additional problems occur after applying such operations that are related to the role of maps within the service. Maps not only describe spatial distributions of phenomena, but they also provide interfaces to integrate information and allow the user to orientate themselves within the data space. In order to fulfil this role, the map interface needs to maintain the integrity of the reference between the user's location and the data being displayed. This is both in terms of the absolute position, for example obtained by using a GPS, and their location in relation to the topology of features that structure the locale. In this sense, the map must be able to preserve situational aspects of place that a user can use during their activities.

8.1.3 Needs for Dynamic Views

Underlying these approaches presented in this chapter is the need for techniques that allow the view to independently re-organise the graphical presentation of information at the moment that it is generated. This should be performed under a set of particular conditions:

1. The relationship between the user's absolute position and the features of interest should be maintained. That is, it must be possible to project the user's position in such a way that their spatial relationships to the information being presented is faithful to how they will experience that information in the real world.

2. The configurations of the most important static geographic features (e.g. roads, paths and rivers), and relationships of the dynamic data with these should be preserved. More generally, the topological and spatial relationships between the main structural features of the map, for example containment within cycles of a road network and adjacency with rivers, and the foreground data should be preserved. For instance, a foreground feature should always remain on the same side of a structural, background, element.

3. The spatial relationships amongst the dynamic features (i.e. spatial patterns amongst points of interest) should be conserved.

4. The amount of overlap between dynamically generated symbols should be minimised, and thus interaction with the displayed data enabled.

8.2 Transformational Approaches to Map Organisation

The method to seek a solution to the needs described above in Section 8.1.3 will be through the development and comparison of three techniques for re-organising points-of-interest (POIs) to enhance their visualisation and ability to be explored, that are based on the characteristics of the underlying properties of map space. This can be thought of as being distorted in order to move the points. This perspective therefore couches the problem of displacement in terms that are more similar to those for map projection between different coordinate reference systems. This conceptualisation is not entirely without precedence. Jäger (1991) describes how a "displacement topography" can be modelled. This describes displacement parameters as a continuous field, not unlike the magnification field that will be discussed later in Section 8.2.3. Figure 8.1 reproduces his example of such a displacement topography.

At least in an intuitive sense, (Ruas, 1998, p. 791) also discusses the problem of displacement in similar terms in saying; "Displacement can be viewed as a set of

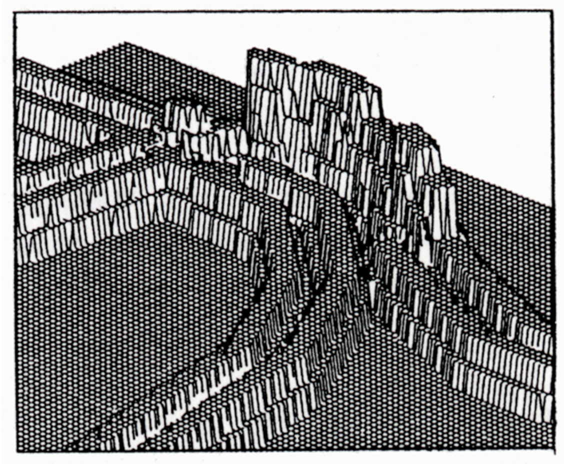


Figure 8.1: Visualisation of a displacement topography from (Jäger, 1991, p.254)

localised distortions in a continuous field" (p.790). The figure she uses to illustrate this idea is reproduced in Figure 8.2.

At least for the first two methods that will be presented here, the reason for following this approach is that it should help maintain the reference between the user's location and the information in the map. These two methods are both based on grid data structures that discretise the map space and perform the reorganisation by distorting it. The third technique is based on a similar method of considering how the space is deformed, but it uses a triangulation instead to discretise the space in a way that is directly dependent on the relationships between objects. In the following sections first a discussion is made concerning the approach in respect to the theory. Then the different methods are presented in more technical detail. In the following chapter (Chapter 9), a comparison of the results is will made empirically and quantitatively.

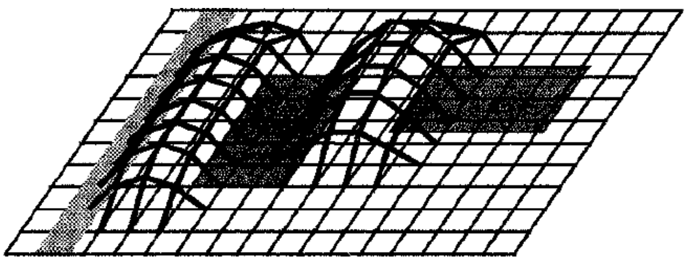


Figure 8.2: Visualisation of a manifold proportional to the proximity between objects from (Ruas, 1998, p.791)

8.2.1 Maps as representational media

Maps communicate information in two principle ways: symbolically and spatially (Berendt et al., 1998). Symbolic information is represented explicitly by using graphical variables (e.g. the size, shape and colour of a symbol) to present selected qualities of the phenomenon of interest. Spatial information is represented implicitly through the spatial arrangements and positioning of the information. Communicating information in this way is often described as by *analogy* (Palmer, 1978), in the sense that the spatial characteristics that constrain the map medium are made analogous to those constraining geographic space (Sloman, 1985).

Patterns of spatial information can be considered in three ways. As spatial configurations of features, as variations in the intensity of a phenomenon at different places on a map, and as particular (absolute) locations of individual data items. Which of these patterns is most relevant will depend strongly on the type of phenomenon being described (MacEachren, 1994). The former two types of relationships can be related to the model of spatial analysis that describes the structure of spatial autocorrelation. This is defined in terms of first and second order spatial variation (c.f. Atkinson and Tate (2000) and O'Sullivan and Unwin (2003)). First order spatial variation relates to the degree to which the distribution of data points is influenced by some underlying property of the geographic space. Second order spatial variation relates to the degree to which local interactions amongst features will effect the resultant distribution. First and second order variation usually both occur within any given data set. For example concerning the WebPark data, the density (or intensity) of observations of deer is likely to vary partly because of the influence of underlying biotic and abiotic factors, such as vegetation and thus what the deer may forage on and the state of the topography. However, the arrangement of deer observations is also likely to be partially dependent on social and behavioural aspects of the animals, such as herding and competition. The last form of spatial pattern relates more to the isolation of, and differentiation amongst, particular data entities. What is special about a place and why it is different to others. Here, space is considered as a graphical variable, position, exactly in the way described by Bertin (1983).

The two dichotomous forms of spatial and symbolic information communication do not generally sit happily together. Symbolising features on a map, beyond their real world footprint, necessarily impacts on the ability of the map to represent configurational and positional spatial patterns. This is caused by two inter-related mapping aspects, the form of portrayal and the scale selection.

- *Portrayal* relates to the selection and application of a set of graphical styles that will be used to communicate salient qualities of the information symbolically. Different schemes of portrayal will have different effects on the ability to describe spatial relations.

- The *scale* further affects the way in which the extensional dimensions of the symbol will scale relative to the scaling of the properties of space.

Figure 8.3 illustrates how these conflicts interrelate. The figure shows how the distance in map units between two point circle symbols of areas 0 (i.e. without symbolisation), 0.5, 1 and 2 mm^2 changes with scale. It can be seen that the scaling rates are dependent on the property of the symbol, here varied by size. Hence the larger the symbol the faster the degradation of spatial relationships as scale is decreased. Maps are always portrayed at some scale, so these effects are always evident. However, they are particularly marked in mobile information services where the resolution of the device requires larger symbols than would be required for other display media.

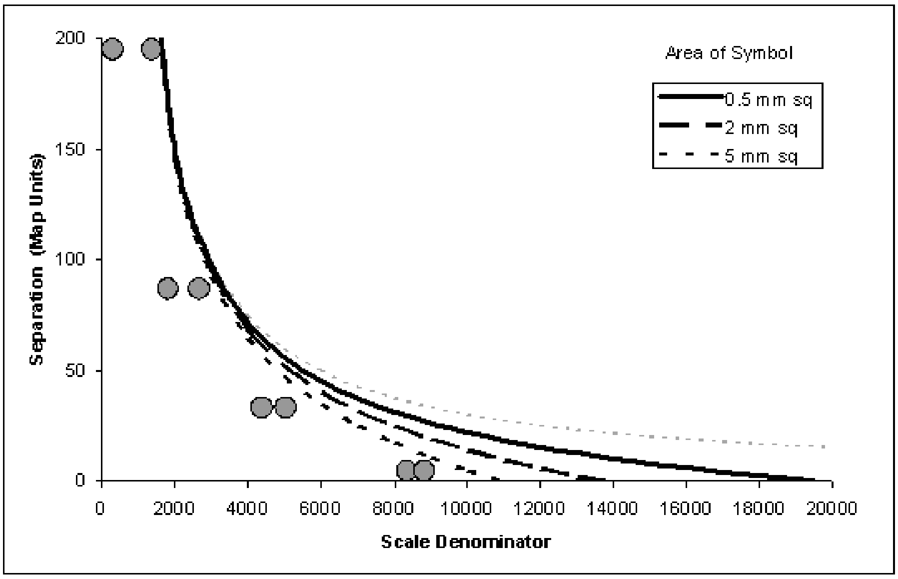


Figure 8.3: Scaling, representation and spatial relationships

Representing phenomena as strongly spatially dependent distributions, such as continuously varying fields of intensity, likewise impacts on the ability to describe information symbolically, since the number of graphical variables that can be shown is severely reduced. Figure 8.4 illustrates different schemes of portrayal for a spatial distribution, showing how the symbolic abstraction must be reduced to emphasise the spatial patterns.

The first example in Figure 8.4 describes data on animal observations by emphasising symbolically the attributes of each individual observation. It uses large heterogeneously shaped icons which allow rapid identification of the principal type and relative number of animals observed at each location but because of this it is limited in its ability to describe spatial relationships between observations. The second example describes information about the diversity in types of animal observed at the same location. It takes a more balanced approach between the symbolic and spatial aspects of the information by using smaller, more homogeneously looking icons with diversity shown as a pie chart graphic. More information about spatial

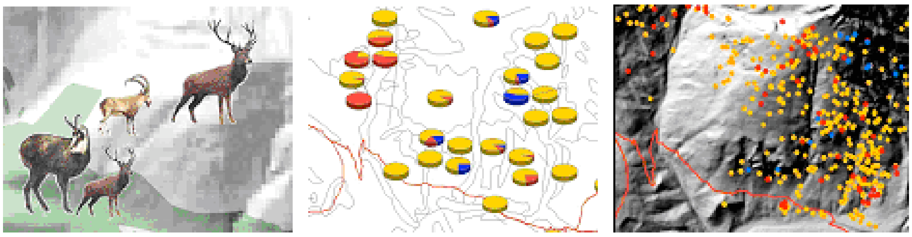


Figure 8.4: Portrayal schemes showing differing degrees of spatial relationships

arrangement amongst locations is provided but at the cost of less readily understandable attribute information for any one observation. The third example uses simple coloured dots to describe locations and number of animals observed. It emphasises the spatial aspects of the information such as the pattern of density and distribution but is limited in what it can further describe about the attributes of the information or about the characteristic of any one site.

8.2.2 Modelling the Map Space

Whenever a form of portrayal to communicate information through a map is adopted, it must be accepted that this choice will have a knock-on effect on the ability to communicate spatial relations. The impact of symbolisation on space can be considered according to whether it is viewed as relative or absolute. Viewing space as absolute, the symbol is thought of as covering a region of space, or consuming *white space*. Viewing space relatively, the impact of symbology is to conserve the space around a feature by re-distributing it. Figure 8.5 illustrates these perspectives for a set of point features viewed in terms of absolute and relative space.

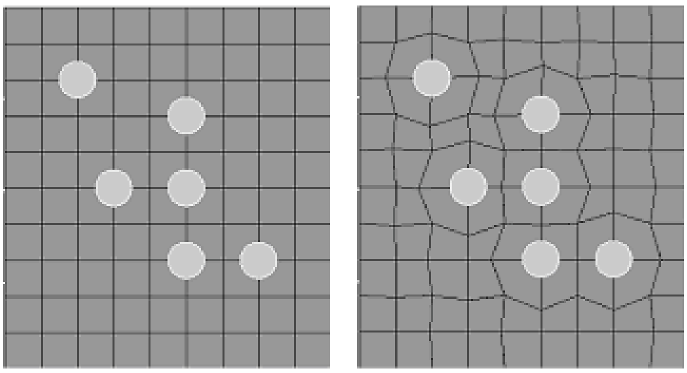


Figure 8.5: Distortions of space and spatial relations caused by symbology, in absolute (left) and relative (right) terms.

In Figure 8.5 the grid in the background is used to represent the underlying space as a coordinate system in which points can be located. If only those points of space where the grid lines cross are considered, we can see that for the absolute view there are points that are covered by the symbol. For the relative view these same points are preserved because they have been pushed away from the symbol. The only point that is covered by the symbol is the location of the symbol itself, all other points within the grid can still be indexed. The advantage of this approach is that if a person is located with a GPS and positioned in the reference system of the relative grid in Figure 8.5, they always remain next to the feature rather than underneath it.

This dichotomy of how to model space is often found in techniques to perform map generalisation, and described in terms of *object-primary* and *space-primary* representations. Here, a model of the map space is necessary for a number of reasons: to identify the spatial relationships that should be preserved at different map scales, to determine where and when feature conflicts are likely to occur due to a chosen symbolisation scheme, to evaluate extrinsic relationships between generalisation states and, to make continuous space more manageable by discretisation. Various techniques exist to meet these needs. They differ in terms of how they represent space and the spatial relationships they abstract. On the one hand, space-primary representations model space and its properties explicitly, usually using a geometric tessellation. Dutton (1998) and Li and Openshaw (1993) provide examples of these in map generalisation. On the other hand, object-primary models represent space as the relationships amongst geographic features (Molenaar, 1998). Examples of these are: minimal spanning trees (Regnauld, 2001), partitions (Brazile and Edwardes, 1999; Edwardes and Mackaness, 2000), Voronoi diagrams (Hangouët, 2000) and Delaunay triangulations (Ruas, 1998; Ware and Jones, 1998), though the latter can be used in either sense.

The remaining sections of this chapter will describe a number different computational methods that employ a relative, space-primary models of map space. These have been used to implement portrayal operations for reorganising map features, similar to the task of displacement in map generalisation.

8.2.3 Variable-Scale Projections

The relative view allows the problem of re-organising the map features to be described in terms of a map projection. Here, the projection is formulated in such a way that the scale is varied according to the density of the underlying foreground information. This means where there are many points the scale is increased, resulting in their separation, and where there are few the scale is decreased, to absorb the increases, or kept the same.

An extension of the "variable scale", or "fish-eye projection" can be considered to illustrate the concept. Harrie et al. (2002) and Rappo et al. (2004) present such projections. The approach of Harrie et al. (2002) is shown in Figure 8.6 applied to a topographic map of Zürich. Here the map scale varies locally within the map space from a single circular region at a constant, larger, scale decreasing to a constant, smaller scale, in the rest of the map space.

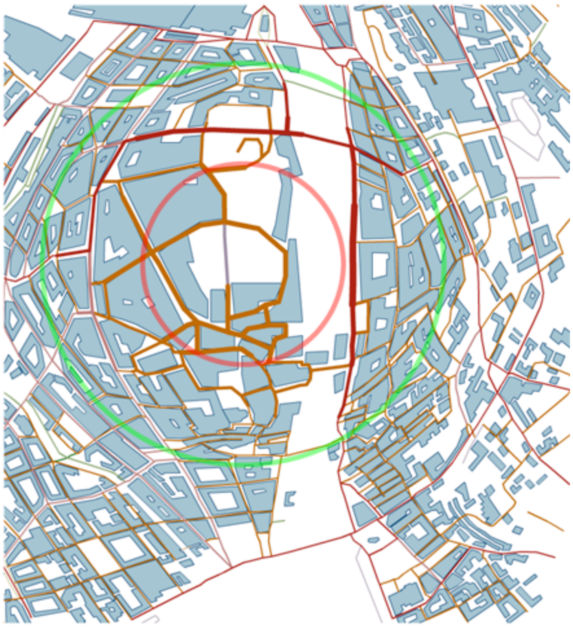


Figure 8.6: Variable scale projection implementing the method of Harrie et al. (2002) applied to a topographic map. The central red ring shows the limit of the larger scale focused on a single location. Beyond the outer green ring the map returns to a smaller base scale. Between the two rings is a smoothly varying scale transition.

The formula for transforming from source to fisheye coordinates is given by (Sarkar and Brown, 1992, p.85) as:

$$P_{feye} = \mathcal{G}(P_{norm})D_{max} + P_{focus} \tag{8.1}$$

where

$$\mathcal{G}(P_{norm}) = \frac{(d+1)\frac{D_{norm}}{D_{max}}}{d\frac{D_{norm}}{D_{max}} + 1} = \frac{d+1}{d + \frac{D_{max}}{D_{norm}}} \tag{8.2}$$

Here, the point P_{focus} is the focus of the projection. The Equation 8.1 is applied independently to the x and y coordinates of the point, P_{norm} transforming it to a point P_{feye}. D_{max} in this equation is the maximum distance over which the transform should take place, for example the distance between boundary of the screen and the focus. Equation 8.2 describes the transformation function $\mathcal{G}$. Here, D_{norm} is the distance between the point being transformed (P_{norm}) and the point of focus (P_{focus}). The constant d is termed the *distortion factor*. Varying it changes the amount of magnification around the focus.

The extension in this work is to think of the operation of symbolising a point as magnifying the neighbourhood of that point in proportion to the size of its symbol. This local scale deformation is then gradually absorbed across the map to bring the space back to its original scale.

There are a number of challenges to this approach. The main problem with fish-eye projections is that they only have a single point of magnification, or focus. Where they have been employed for LBS this has been about the user's own position. However, to be used to reconfigure many symbols they need multiple foci. In addition the distortions of space that are induced do not preserve spatial relationships in ways that are easily controllable, the reasons for this are discussed later in Section 8.2.5. Further, the distortion is difficult to limit locally and can therefore affect other features some distance from a group of conflicting symbols.

A number of authors have sought to overcome the problem of single foci (Kadmon and Shlomi, 1978; Carpendale et al., 1997; Keahey, 1997). Keahey (1997) presents a technique that overcomes the issue of multiple foci, which he calls *non-linear magnification*. He uses the approach both for assisting the exploration of general information repositories through detail-in-context visualisation, as well for thematic cartography (Keahey, 1999). His approach draws on a decomposition of the problem domain described by Leung and Apperley (1994) which separates out two interrelated functions, a transformation function and a magnification function. As they describe:

> "A distorted view is created by applying a mathematical function, which is called a transformation function, to an undistorted image. The transformation function for a presentation technique defines how the original image is mapped to a distorted view. A magnification function, which is the derivative of a transformation function, on the other hand provides a profile of the magnification (or demagnification) factors associated with the entire area of the undistorted image under consideration." (Leung and Apperley, 1994, p.130)

Figure 8.7 illustrates the relationship between the two functions.

8.2.4 Keahey-Tobler Grid Approach

Keahey's method is to define a scalar field over a grid that describes the desired magnification function at different points of the space. Using this he computes the transformation function, essentially as the anti-derivative. This is a non-trivial problem because it involves finding a way to convert from a single magnification value to a two-coordinate transformation, which in general is not uniquely defined (Keahey, 1997, p.69). To approximate the transformation function over the grid he presents a mesh based algorithm that iteratively moves the nodes in such a way as to resize the cells and meet their desired areas as defined by the magnification function. An approach that shares similarities to earlier work by Tobler (1973) for constructing cartograms. At a given point, the amount of push or pull is performed equal for each direction (i.e. along each edge meeting at a node), which helps to ensure that transformation is performed in an even way. Figure 8.8 illustrates how the algorithm works by iteratively pushing and pulling the neighbours of a point

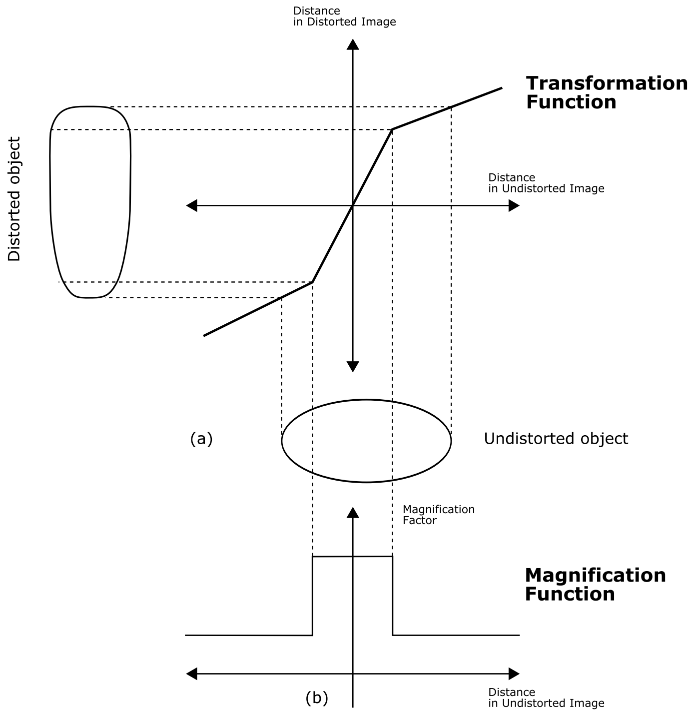


Figure 8.7: The relationship between the transformation function and the magnification function. a) Transformation of an ellipse by applying the transformation in one dimension. b) The corresponding magnification function. Figure from (Leung and Apperley, 1994, p.131)

until convergence is reached. Convergence is computed using the the root mean square error evaluated over each the area grid cell with respect to its target area.

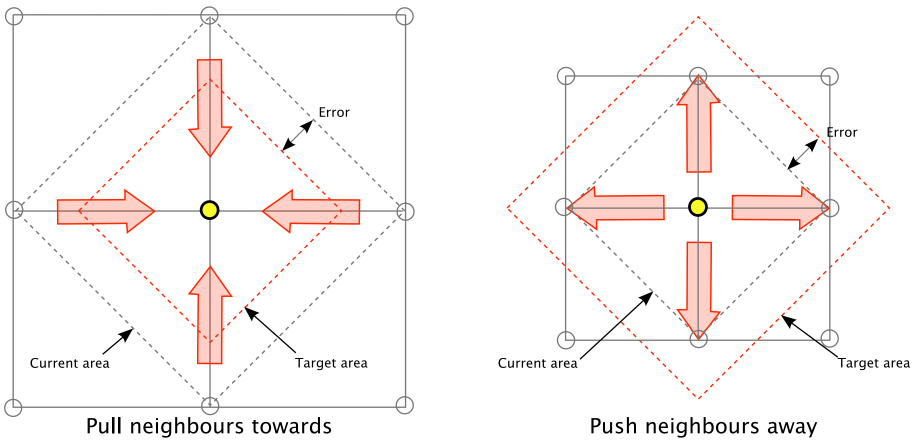
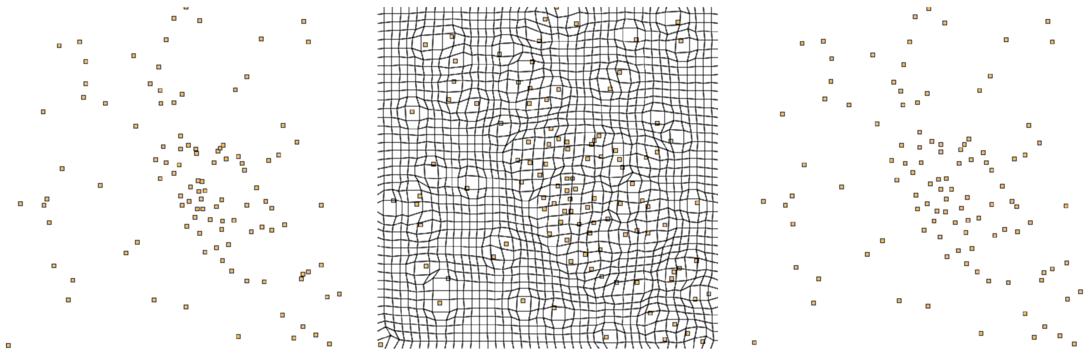


Figure 8.8: The mechanics of the algorithm for non-linear magnification by Keahey (1997)

The approach of non-linear magnification is adapted to the problem here of reorganising points-of-interest. The transformation method will be termed the KT-grid (Keahey-Tobler grid), since it is based on top of a regular square mesh. In order to define the nature of the transformation, scalar values need to be defined over the cells of the grid that reflect the magnification caused by the symbolisation of linear and point features. For points, the symbology is simply added into the cell where it falls (more detail of how this is done is provided later in Section 8.2.8). Figure



(a) The point set (b) The transformed grid (c) Re-positioned points

Figure 8.9: The KT-grid used for re-organising symbolised points under a non-linear transformation induced by the symbology.

8.9 illustrates the process applied to a set of points, showing, in the centre, how the grid is transformed by the symbolisation.

The points are re-projected by computing a bilinear transformation between the source grid square and the transformed quadrilateral. Based on this a point inside the source grid square can be re-projected into the transformed cell. Equation 8.3 describes how the projected coordinates are computed using the forward mapping of the bilinear transformation from the unit square to an arbitrary quadrilateral with coordinates $x_0, y_0 \ldots x_3, y_3$.

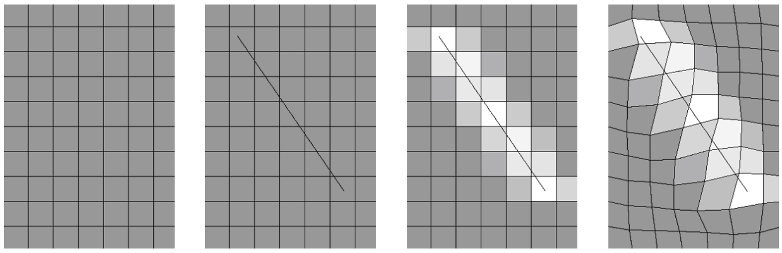
$$\begin{aligned} x_{new} &= a_0 x + a_1 x + a_2 y + a_3 xy \\ y_{new} &= b_0 y + b_1 y + b_2 y + b_3 xy \end{aligned} \tag{8.3}$$

Where the a_i coefficients ($i = 0 \ldots 3$) are given by:

$$\begin{aligned} a_0 &= x_0 \\ a_1 &= x_1 - x_0 \\ a_2 &= x_3 - x_0 \\ a_3 &= x_0 - x_1 - x_3 + x_2 \end{aligned} \tag{8.4}$$

The b_i coefficients ($i = 0 \ldots 3$) are in the same form as the a_is substituting the y_j values for x_js ($j = 0 \ldots 3$).

To compute the magnification field for the linear features a rasterisation type process is performed over the line. The anti-aliasing rasterisation technique of Gupta



(a) (b) (c) (d)

Figure 8.10: The method of parameterising the magnification field for a linear object. a) The grid data structure that represents the map space and that will hold the scalar magnification field. b) The grid and line whose symbology is to be added. c) The magnification field on the grid, the lightness of the colour indicating how high the value has been set, i.e the white coloured cells have the highest values. The pattern is due to the anti-aliasing rasterisation. d) The distortion induced by the magnification values.

and Sproull (1981) is adapted for this because it ensures all cells surrounding the line will have a magnification value set. Figure 8.10 illustrates the procedure. Figure 8.11 shows the process applied to a road network. Here the amount of magnification has been exaggerated to better visualise the effect.

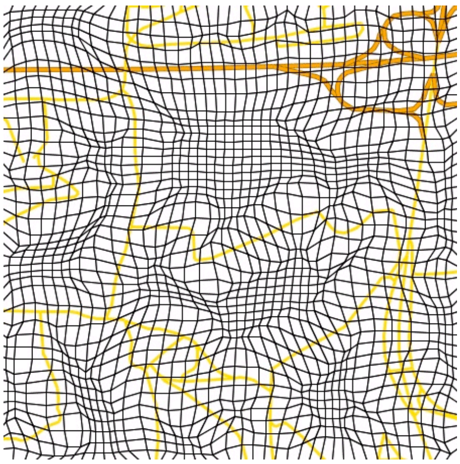


Figure 8.11: Shows the effect of the non-linear magnification on the map space when parameterised according to road network symbolisation. The network itself has been left untransformed.

It is clear in Figure 8.11 that the transformation must conserve the overall map space, thus where the map space is magnified elsewhere it must be reduced. Because of this, the transformation will cause the map space to spread out towards areas where no magnification, beyond maintaining the unit area of the cell, has been defined. Whilst for points this is the basis of the map re-organisation, for maps with points *and* lines it is problematic since it means that the points can move over the lines. Including the symbolisation of the lines in the magnification field helps to overcome this problem to a certain extent, because a gradient is created that helps ensure the transformation moves points away from roads. However, this is a weak method for implementing topological constraints since the areas where the symbology of the lines has been added to the magnification field will also drift. The ideal would be to set internal boundary constraints on the transformation that would fix the movement of the map space under the transformation at certain points. The simplest way of achieving this would be just to pin the cells lying underneath the lines, so that the transformation must always be forced away from line work and the topology preserved. The difficultly here is that it would also over constrain the operation, preventing points close to the road from being moved at all.

8.2.5 Intrinsic Properties of a Surface

Two important issues are highlighted in the KT-grid approach. One is the problem of defining an appropriate function for transformation. The other is defining ways of constraining the transformation to respect certain boundaries such as roads. This latter problem will be considered later in Section 8.2.7. Here, the problem of characterising a transformation in a more rigorous way will be considered and its implementation within a framework for reorganising map features presented.

The issue of defining a transformation is commonly encountered in cartography in the construction of map projections (Snyder, 1987) and continuous cartograms (Tobler, 2004). Figure 8.12 illustrates the cartograms from a number of researchers. It is also important in other domains, such as in computer graphics in the areas

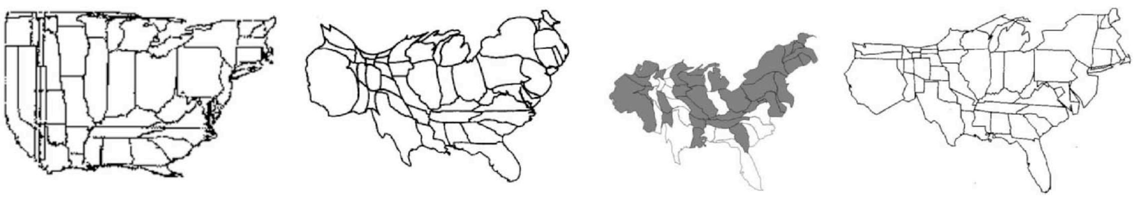


Figure 8.12: Area cartograms (1) Tobler (1986) (2) Gusein-Zade and Tikunov (1993) (3) Edelsbrunner and Waupotitsch (1997) (4) Kocmoud and House (1998). Figure from Keim et al. (2005)

of image warping (Wolberg, 1990) and surface parameterisation (for a review see Floater and Hormann, 2005). Surface parameterisation can be simplistically described as looking for ways to flatten a surface in a three dimensional space onto a two dimensional parameter plane. Such a need is often encountered in mapping textures to surfaces (Heckbert, 1986; Haker et al., 2000).

Map projections transform between a mathematical representation of the earth's surface that is curved and one that is a flat plane. Such a transformation cannot be defined without introducing distortions in distances, angles, areas, directions, and the shapes of continents and countries (Monmonier, 1993). To cope with these problems different map projections have been defined that seek to compromise between the type of distortion and the intended use of the map. Of particular interest here are the distortion of angles and areas. Map projections that preserve areas, at the expense of angles, are termed equal-area, equiareal, equivalent or authalic. Those that (locally) preserve angles, and therefore (locally) shapes, are termed conformal or orthomorphic. Examples of equal-area projections are the Lambert azimuthal projection and the sinusoidal projection (Snyder, 1987). Examples of conformal projections are the Mercator and the stereographic projections (Snyder, 1987). The relevance to the concern here of defining a variable scale transformation is that it is also precisely these distortions that need to be controlled. Controlling the area distortion provides the ability to distribute the area in the transformation according to the underlying information density. The ability to preserve angles provides a constraint with which to ensure that spatial relationships between transformed foreground information are as far as possible managed.

Mathematically, these two types of distortion are directly related to what are termed the *intrinsic* properties of a surface. These properties are metrics of a surface that are independent of its shape (Casey, 1996). That is, if the surface is bent (but not stretched) these properties will remain unchanged. For instance, the intrinsic geometry of a piece of paper is not changed by folding into a cylinder or cone. The intrinsic properties of a surface can be examined by describing it in its parametric form. Here, a rectangular coordinate patch is defined whose coordinates provide parameters that allow the surface to be described functionally. As such, the mapping (in the mathematical sense of the word) is a function that transforms between two multi-dimensional spaces, i.e. $F : \mathbf{R^n} \to \mathbf{R^m}$. This function is completely described by m real-valued functions on $\mathbf{R^n}$, such that for a point p of $\mathbf{R^n}$, $F(p) = (f_1(p), \ldots, f_m(p))$. These functions are termed coordinate functions. For example, if the coordinates of the parameter space are named u and v a point (x,y,z) on a surface in a three-dimensional space can be described by coordinate functions $(x(u,v), y(u,v), z(u,v))$. For instance, the coordinate functions of a unit sphere can be defined as $x = \sin v \cos u$, $y = \sin v \sin u$, and $z = \cos v$, where $0 \leq u \leq \pi$ and $-\pi \leq v \leq \pi$.

Of interest here are mappings between two two-dimensional spaces, i.e. $F : \mathbf{R^2} \to \mathbf{R^2}$. These mappings are termed *planar mappings*. Here the domain parameter space can be thought of as the undeformed grid and the xy plane as the transformed grid. The mapping function (F) is differentiable if the coordinate functions are differentiable. In this case, the shape of the surface in the vicinity of a point can be characterised in terms of the partial derivatives of the parameterisation at that location. That is, infinitesimal increments of coordinates can be expressed in terms of infinitesimal increments of the parameters. The derivatives can be visualised by examining what happens to the unit square in the parameter space under a transformation. Figure 8.13 illustrates this for a planar mapping.

The derivatives dx and dy illustrated in Figure 8.13 can be defined in terms of

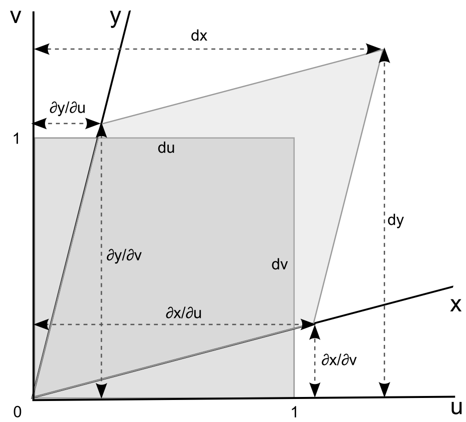


Figure 8.13: Derivatives of a mapping of the unit square into the xy plane.

partial derivatives (Casey, 1996):

$$\begin{aligned} dx &= \frac{\partial x}{\partial u}du + \frac{\partial x}{\partial v}dv \\ dy &= \frac{\partial y}{\partial u}du + \frac{\partial y}{\partial v}dv \end{aligned} \tag{8.5}$$

The partial derivatives themselves can be arranged in a matrix, termed the Jacobian matrix. This provides a linear approximation of the function F at a point:

$$\mathbf{J} = \begin{pmatrix} \frac{\partial x}{\partial u} & \frac{\partial y}{\partial u} \\ \frac{\partial x}{\partial v} & \frac{\partial y}{\partial v} \end{pmatrix} \tag{8.6}$$

The determinant of the Jacobian matrix is then given by:

$$\det(\mathbf{J}) = \frac{\partial \mathbf{x}}{\partial \mathbf{u}}\frac{\partial \mathbf{y}}{\partial \mathbf{v}} - \frac{\partial \mathbf{x}}{\partial \mathbf{v}}\frac{\partial \mathbf{y}}{\partial \mathbf{u}} \tag{8.7}$$

The determinant gives the area of the mapped parallelogram shown in Figure 8.13. More generally, it provides a measure of the rate of change of area at a point. This is important here because by specifying what the determinant should be the distribution of the area can be changed according to the underlying density of information (Tobler, 2004).

As can be seen in Figure 8.13, the partial derivatives can be thought of as two vectors emanating from the point at which the derivative is relevant. Information about the length of these vectors and the angle between them can be obtained by taking the inner product of this matrix with itself, that is, by multiplying the transpose with the matrix itself.

$$\mathbf{J^T J} = \begin{bmatrix} \left(\frac{\partial x}{\partial u}\right)^2 + \left(\frac{\partial y}{\partial u}\right)^2 & \frac{\partial x}{\partial u}\frac{\partial x}{\partial v} + \frac{\partial y}{\partial u}\frac{\partial y}{\partial v} \\ \frac{\partial x}{\partial u}\frac{\partial x}{\partial v} + \frac{\partial y}{\partial u}\frac{\partial y}{\partial v} & \left(\frac{\partial x}{\partial v}\right)^2 + \left(\frac{\partial y}{\partial v}\right)^2 \end{bmatrix} \tag{8.8}$$

This matrix is described as the metric tensor or matrix of coefficients of the First Fundamental Form [1] and usually written:

$$\mathbf{I} = \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix} \tag{8.9}$$

The coefficients are also sometimes called warp functions (O'Neill, 1997) since they describe how the mapping stretches the parameter space in the two opposing directions. Taken individually, the terms g_{11} and g_{22} describe the squared lengths of the two partial derivative vectors. The terms g_{12} and g_{21} define the inner (dot) product of the vectors, which are the same since the product is commutative. Its value describes the cosine of the angle between the vectors multiplied by the their lengths. If the vectors are normalised, its value ranges from one when they are parallel to zero when they are perpendicular. If the two vectors are perpendicular the stretches given by the values of g_{11} and g_{22} are independent of one another. If they are parallel the mapping is degenerate since the vectors are not linearly independent. For other values, the maximum and minimum eigenvalues (λ_1 and λ_2) and eigenvectors of I are required instead (found for example using singular value decomposition) to determine the amount of independent stretching in orthogonal directions (Degener et al., 2003). In fact, these are precisely what are shown by the Tissot indicatrix in cartography. Floater and Hormann (2005, p.163) describe the following equivalences:

$$\begin{array}{llcll} \text{F is isometric} & \Leftrightarrow & \mathbf{I} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} & \Leftrightarrow & \lambda_1 = \lambda_2 = 1 \\ \text{F is conformal} & \Leftrightarrow & \mathbf{I} = \begin{pmatrix} \eta & 0 \\ 0 & \eta \end{pmatrix} & \Leftrightarrow & \lambda_1/\lambda_2 = 1 \\ \text{F is equiareal} & \Leftrightarrow & \det \mathbf{I} = \mathbf{1} & \Leftrightarrow & \lambda_1\lambda_2 = 1 \end{array} \tag{8.10}$$

Hence, $\mathbf{I}$ provides a method to characterise a mapping. When the derivative vectors are orthogonal and their lengths proportional the mapping will be conformal at that point. If the volume of the stretch is the unity the mapping will have preserved the area at that point, though clearly this need not be uniform, e.g. a stretch of a third in one direction and three times in the other will preserve the volume but will have distorted the shape. If the mapping satisfies both the conformal and equiareal conditions then it is isometric and preserves distances.

These descriptions allow the mapping to be formulated in terms of *mutual energy* (Desbrun et al., 2002). This compares two surface representations and returns a

[1]The First Fundamental Form itself is the equation (Floater and Hormann, 2005, p. 160):

$$\begin{aligned} ds^2 &= dx^2 + dy^2 \\ &= g_{11}du^2 + 2g_{12}dudv + g_{22}dv^2 \\ &= \begin{pmatrix} du & dv \end{pmatrix} \mathbf{I} \begin{pmatrix} du \\ dv \end{pmatrix} \end{aligned}$$

This describes the square of the length of an infinitesimal arc in the transformed space.

real value representing the difference between them. Here the concern is between the representation in any particular state, for example the initial state, and an ideal surface defined by a particular parameterisation. The energy can then evaluated by integrating the individual values of the energy at all points. The objective is then to minimise this energy. The energy can be formulated as a functional of two component functions, one that measures the deformation of areas and the other that measures the deformation of angles. The aim is that the distribution of the area deformation should match the scalings given by the underlying symbology and that the deformation of angles should be as conformal as possible.

A number of researchers have couched related mapping problems in these or similar terms. To consider the area component of the transform, Tobler (1973, 2004) uses the determinant of the Jacobian ($\mathbf{J}$) multiplied by the scale factors required to generate a cartogram. To limit the deformation of angles he minimises the Dirichlet energy. This can be written as a set of inequalities (Desbrun et al., 2002, p. 213):

$$\begin{aligned} \text{Area of a patch } M &= \tfrac{1}{2}\int_M |f_u \times f_v|\, dudv \le \tfrac{1}{2}\int_M |f_u|\,|f_v|\, dudv \\ &\le \tfrac{1}{4}\int_M (f_u^2 + f_v^2)\, dudv = \text{Dirichlet Energy} \end{aligned} \tag{8.11}$$

These inequalities hold with equality only when partial derivatives are orthogonal and their norms (squared lengths) proportional and so when the mapping is conformal. Hence the Dirichlet energy can be seen as based around the sum of the diagonal components of $\mathbf{I}$, when it has been defined within an orthonormal basis as it is in the equivalence equations described previously in Equation 8.10, and thus as integrating the trace of $\mathbf{I}$ ($tr(\mathbf{I})$) (Pinkall and Polthier, 1993). In surface parameterisation the situation is slightly different in that a three-dimensional surface is being mapped to a two-dimensional parameter plane. Assuming the surface is not flat, in which case the parameterisation is already determined, the mapping can be defined in terms of only the deformation of angles. For example, if the surface is represented using a triangulation the sum of the angles where a ring of triangles are meeting at a point will not equal 2π. Therefore, the problem can be defined in terms of one of minimising the distortion of angles. Pinkall and Polthier (1993) use the Dirichlet energy for this purpose, presenting a discrete method of computing it for a triangulated surface that has been highly influential to other approaches. Hormann and Greiner (2000) and Hormann (2001) define the MIPS (Most Isometric ParameterizationS) energy. This is the Dirichlet energy divided by the determinant of the Jacobian, essentially giving the Dirichlet energy per unit of parameter area. Desbrun et al. (2002) also use the Dirichlet energy but in addition define an areal energy (the Chi-energy E_χ) based on the curvature of the surface at a point and related to the Second Fundamental Form. They then define a general energy based on the weighted sum of these two component ones:

$$E = \lambda E_{Angle} + \mu E_\chi \tag{8.12}$$

Here the weights (λ and μ) allow a trade-off between area and angle distortion. Degener et al. (2003) likewise describe a composite energy with allows compromises between areas and angles. For the conformal part they use the MIPS energy of Hormann and Greiner (2000), that is:

$$E_{angle} = \sqrt{\frac{\lambda_1}{\lambda_2}} + \sqrt{\frac{\lambda_2}{\lambda_1}} \tag{8.13}$$

where λ_1 and λ_2 are as described in Equation 8.10. For the equiareal part they use an area based on the determinant of the square root of **I**, orthonormalised as described before, which is therefore equivalent to the determinant of the Jacobian (Degener et al., 2003, p. 230).

$$E_{area} = \sqrt{\det(\mathbf{I})} + \frac{1}{\sqrt{\det(\mathbf{I})}} \tag{8.14}$$

The addition of the inverse term ensures that the function is convex. That is, when the determinant is small or large the energy is large. They then define their energy functional as:

$$E_{combined} = E_{angle} \cdot E_{area}^{\theta} \tag{8.15}$$

Here the parameter θ is a weight that can be varied to trade-off the distortion of area against angle.

8.2.6 Functional Grid Approach

The functional grid approach draws on the same basis for non-linear magnification as described in Sections 8.2.3 and 8.2.4, that is, of having separate magnification and transformation functions, see Figure 8.7. However, to perform the transformation it employs the formulation of Degener et al. (2003) described in the last Section. Their approach was used because it was well suited to planar mappings i.e. between surfaces with zero curvature, whilst at the same time allowing selective control over the distortion of areas and angles. In comparison to the KT-grid approach it also has the advantage that it can be computed from an initial surface composed of arbitrarily shaped quadrilaterals rather than a regular grid. This is important because it means that the initial grid, on which the magnification field is implemented, can be shaped and constrained in such a way as to ensure that the transformation respects the topology of linear features. The procedure to allow this is described in Section 8.2.7.

The formulations described in Section 8.2.5 formulate the problem in terms of a continuous mapping. For the purposes of computation, the continuous case needs to be defined linearly for a surface represented using discrete elements. The discretisation consists of two aspects, how to represent the space and how to represent the function that defines the mapping in a discrete manner. Two representations of the space are described here, a network of quadrilaterals and a triangulation based on the map features.

The quadrilaterals were defined using a four way node-edge topology. That is, a quadrilateral (face) is bounded by four cornering nodes and four edges (the sides). Each node is connected to four neighbouring nodes by four neighbouring edges, some of which may be null at the boundaries. Figure 8.14 illustrates the important components of the quadrilateral that are influenced by the transformation. For clarity, the components are only shown for the top left quad. In Figure 8.14 two

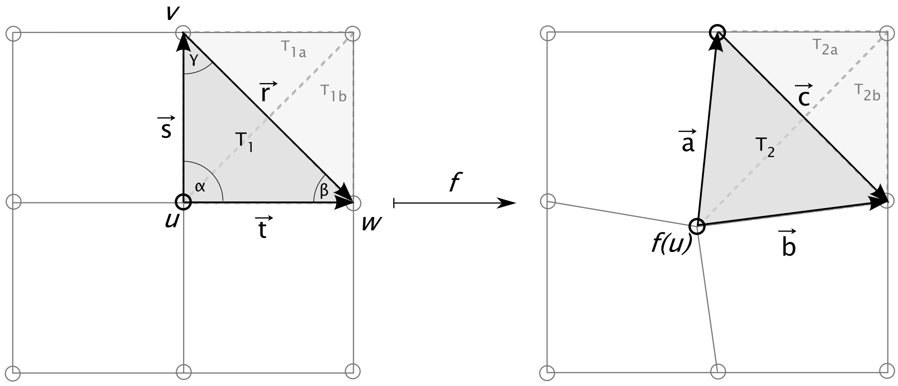


Figure 8.14: The components of a parameter space effected by mapping f applied to a single point $\mathbf{u}$

types of triangle are highlighted. The grey triangles (T_1 and T_2) illustrate how the area of a quadrilateral is changed by moving the point $\mathbf{u}$ under the mapping f. The vectors $\mathbf{s}$, $\mathbf{t}$, and $\mathbf{r}$ are mapped to the vectors $\mathbf{b}$, $\mathbf{c}$ and $\mathbf{a}$. Hence, the angles α, β, and γ are changed. The same set of relationships can also be computed between the triangles marked T_{1a} and T_{2a}, and T_{1b} and T_{2b}. This is necessary to take into account all the properties that are disturbed by moving the point $\mathbf{u}$. The details of these are omitted from the diagram for the sake of clarity. Pinkall and Polthier (1993, p. 20) give a formulation for describing the Dirichlet energy ($E_D(f)$) between the two triangle in terms of the angles and vectors shown:

$$E_D(f) = \frac{1}{4}(\cot\alpha\,|\mathbf{a}|^2 + \cot\beta\,|\mathbf{b}|^2 + \cot\gamma\,|\mathbf{c}|^2) \tag{8.16}$$

In the MIPS energy of Hormann (2001) this becomes,

$$E_{MIPS}(f) = \frac{(\cot\alpha\,|\mathbf{a}|^2 + \cot\beta\,|\mathbf{b}|^2 + \cot\gamma\,|\mathbf{c}|^2)}{|\det(A_2)|} \tag{8.17}$$

where $|\det(A_2)| = \|\mathbf{b} \times \mathbf{c}\|$. This means that retaining the angles of the original space can be used as a constraint to control the deformation of the angles in the transformed space. The discretisation of the area energy is given by Degener et al. (2003, p. 231) as simply,

$$E_{Area}(f) = \frac{\text{Area}(T_2)}{\text{Area}(T_1)} + \frac{\text{Area}(T_1)}{\text{Area}(T_2)} \tag{8.18}$$

The total energy experienced by $f(u)$ can be obtained by summing the energies for each triangle and for each quad surrounding this point. Hence, a total of twelve components are summed for each point.

To compute the transform it is necessary to minimise the overall energy. This is achieved by finding the position for each point where the energy of $f(u)$ is minimal, known as the critical point. Without any magnification the points will already be at their minima, so magnification values need to be allocated over the grid cells to drive the energy. This means that the area of T_1 is represented as the true area multiplied by a scale factor that describes the desired expansion. Finding the point where the energy is minimal is achieved using the Polak-Ribiere multidimensional conjugate gradient method (Press et al., 1994, Ch. 10.6). This uses the directions and magnitudes of the partial derivatives of the function at a central point to iteratively move closer and closer towards the minimum. This movement is constrained to lie within the diamond region formed between $f(u)$ and its four neighbouring points, and thus ensure that quadrilaterals remain convex at all times.

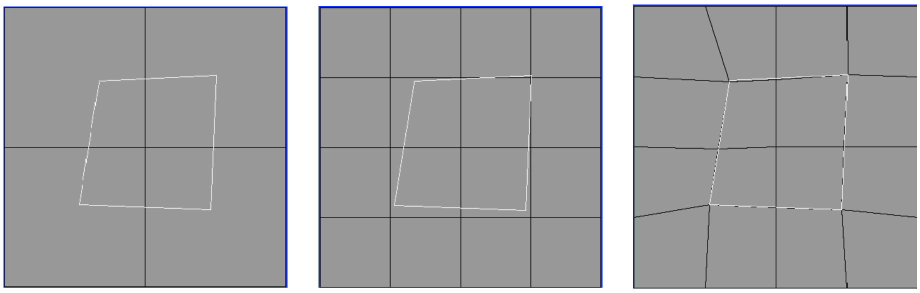
To minimise the energy over the entire grid an iterative relaxation approach is employed. This simply optimises the position of every point on the grid with respect to its starting configuration. The iterations are continued until convergence is obtained or until a set number of turns have been executed.

8.2.7 Feature Alignment

One of the main problems described for the KT-grid is that it is difficult to add topological conditions that will ensure the transformation respects a network of linear features. The functional grid has the advantage that it does not need to assume a regular initial form (i.e. squares) and instead can be made up of arbitrarily shaped convex quadrilaterals. A method was therefore sought to initially fit the shape of the grid to certain map features, such that the linework of a feature would always run along the edge of a grid cell or diagonally across a cell face. The grid could then be pinned at the nodes where the linear features lay. Essentially, this would allow a compromise between a space-primary representation and an object primary one by producing a grid that shared a topology with that of a selection of salient background map features that should be respected. This would mean that the view could still operate in an independent manner and re-organise the foreground information in response to user interactions at runtime, but this process could be enhanced by a knowledge of the topology of background features.

A few researchers have looked at ways of solving this problem. The approach of Hyman et al. (2000) appears to produce very good results, but is quite involved mathematically and is restricted to closed features, i.e. those that completely partition parts of of the map space, completely span it. The approach of Biermann et al. (2001) and Boier-Martin et al. (2004) also shows the promise of good results, but is simpler to implement and without restriction on input geometries. Thus, the latter approach was applied here.

The principle for aligning the representation is to construct a one-to-one mapping between the grid and the features such that any piecewise linear feature curve either follows along mesh edges or crosses mesh faces diagonally. In Biermann et al. (2001) this is termed the *approximation property.* To achieve this property they describe a two step iterative processes of mid-point subdivision of the grid (i.e. splitting every cell into four) followed by snapping grid nodes onto points of the feature curves. The stages are illustrated in Figure 8.15. For the purposes here, the subdivision step is



(a) The initial grid and a feature (b) The refinement step (c) The snapping step

Figure 8.15: The steps for aligning a grid with features from the algorithm by Biermann et al. (2001)

not strictly necessary, instead the grid can be defined as having a specific cell size and a single snapping step can be performed. In the snapping step each grid node is moved onto the closest point of the feature line lying within a distance ϵ of the node. ϵ is calculated as a parametric variable between 0 and 0.5 defined over the unit square. To compute the distance between a node and a point on the feature a linear map is defined that transforms a pair of adjacent edges emanating from a node to the unit square. Snapping can move a node onto a point on an edge of a feature or onto one of the features vertices. However, the vertices are given priority. That is, if a feature vertex is within ϵ of a grid node this is snapped to in preference to snapping to the feature edge even if that is closer.

An issue was how to manage large numbers of connected lines found in geographic data in an effective way. It was observed that the ability to model the neighbourhood of edges around any given grid point was highly desirable. A snap should not move a vertex across a feature, thus knowing which edges were 'visible' from a node could reduce computation. In addition, it would allow a consideration to be made about how uniquely a grid node could be assigned to a single feature or feature edge, which required analysis to be limited to only those features that 'enclosed' a grid node. To fulfil this purpose a spatial index based on a binary space-partitioning tree (BSP) (Foley et al., 1990, pp.555-557) has been implemented, using the feature edges to define half spaces. Figure 8.16 illustrates the BSP. In Figure 8.16 the lines represent map features that partition the space into convex faces. In blue, the face that contains an arbitrary point labelled 'E' is shown. The convexity of

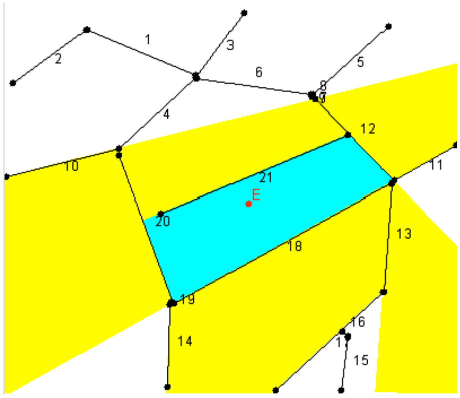


Figure 8.16: Binary space-partitioning tree to identify the closest edges to an arbitrary point labelled 'E'. The containing face is coloured in blue the neighbours of this in yellow

a BSP face has the advantage that edges that make up its border must be visible to the point. In addition it is fast to traverse the resulting tree data structure and establish neighbourhood relationships for any given position. However the data structure can generate large amounts of faces with boundaries that do not support edges. To overcome this limitation, tree-traversal techniques, to find the second order neighbours of a given face were employed. The neighbours are shown in yellow in Figure 8.16.

Because the cells are distorted by the snapping it becomes difficult to identify which grid node is nearest to an arbitrary point. Therefore, a method was also required that would allow the nearest node and containing quad of an arbitrary position to be determined. This was achieved with another half-plane type data structure, where each half-plane is defined by linking the nodes of the grid to their neighbours at different levels. Levels are then connected within a quadtree-like hierarchical tree. A recursive search through the quads based on the relationship between a point and the half-planes for a particular level is then performed to find the closest node. Figure 8.17 illustrates the data structure for two levels. To find the quad containing a point the quads directly neighbouring the nearest node are then used. It should be noted that this method was successful because the grid was defined as a square and the cells were determined through a subdivision process; for grids defined in other ways the index would need to be adapted. The advantage of the approach shown in Figure 8.17 is that, unlike a conventional quadtree it is dynamic. That is, the nodes structuring the tree can be moved, e.g. because of snapping, without affecting the ability to locate the nearest vertex at any later stage. Figure 8.18 shows two examples of grids that have been aligned with the features. Here a fairly coarse grid has been used to emphasise the effect.

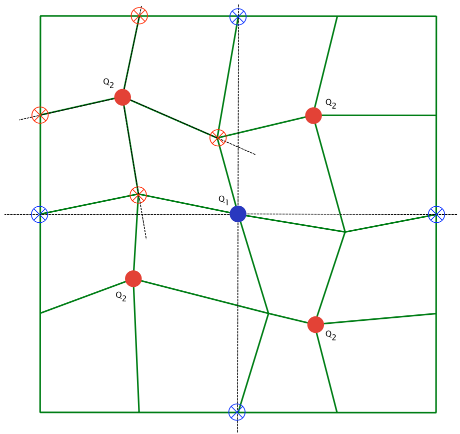
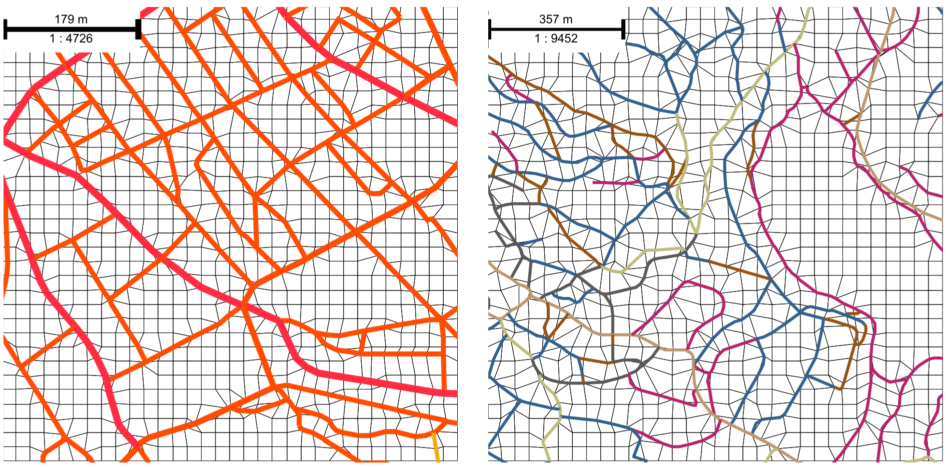


Figure 8.17: Indexing system used to identify the closest grid node to a point. The nodes marked with filled circles represent how the nodes are structured within the tree, i.e Q_1 is the parent node of those marked Q_2. Each node in the tree has a reference to its four adjacent neighbours at a given hierarchy level. The nodes are marked shown by a circle marked with a cross inside. The planes used to determine the direction of traversal through the quads of the tree are shown by extended dashed lines. For the second level only the planes of the top left quad are shown.



(a) Urban example

(b) Rural Example

Figure 8.18: Aligning the grid with features based on the approach of Biermann et al. (2001)

8.2.8 Parameterisation of the Magnification Field

Parameterisation involves defining the values within the magnification field that describe the amount of magnification that each cell should aim to achieve. This in turn is based on the amount of symbology that needs to be accounted for within the region of map space. An individual cell expands from the point at its centre. This means that the amount of displacement linearly is greatest along the sides of the cell and smallest in the middle. In the ideal situation each cell would contain just one point and that point would be situated at the centre, hence all the magnification would take place around the point. However, such a situation is highly unlikely except when the size of a cell is very small. In general, cells may contain multiple points which might be situated anywhere inside. Multiple points within the cell will thus be displaced radially from its centroid. This has conceptual similarities to the displacement approach of Mackaness and Purves (2001) and Mackaness (1994), which displaces features radially from a point of focus that is determined from the centroids of clusters of points. The problem here is to define an expansion that is sufficient to separate points without being too large that they are over displaced.

The method proposed to handle this issue it to divide each cell into four quadrants and assume that the points are distributed uniformly within these. The amount of magnification required to expand a cell is then computed in the worst case.

1. The points falling within a particular cell are organised in a list.

2. The list is then sorted by greatest symbol size first. A quadrant being expanded to account for the largest cell will cause all quadrants to be expanded by the same amount. Hence this is the worst case.

3. If there are more than four points in the cell, there must be more than one in a quadrant, so the maximum number of points (n) that can be in a quadrant, assuming a uniform distribution within the quadrants, needs to be found. This is just the whole part of the number of points divided by four (the number of quadrants). The remainder, $r = n \bmod 4$, is also computed.

4. In the worst case the biggest points will all be in the same quadrant so areas of the n greatest symbol sizes are summed.

5. A fraction of the next largest symbol, the remainder divided by four ($r/4$), is then added to this to account for the probability that this too falls in the same quadrant giving an area $\mathcal{A}$.

The amount of expansion is then computed by envisaging the ideal situation of a square cell whose area is equal to that of the actual cell's area and a single symbol in one of the quadrants whose area is equal to $\mathcal{A}$. In this situation, the expansion needs to be sufficient that the distance between the sides of the symbol and the sides of the quadrant is the same as the distance between the center of the quadrant and the centre of the cell. Figure 8.19 illustrates this. Here the amount of expansion needs to be sufficient that the distance $d2$ is equal to the distance $d1$(computed before magnifying). Accounting for the symbolisation of linear features is more

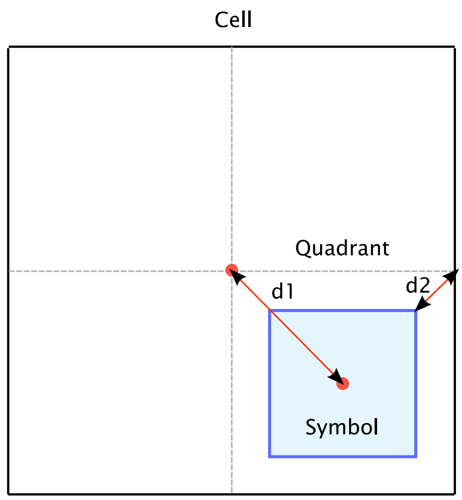
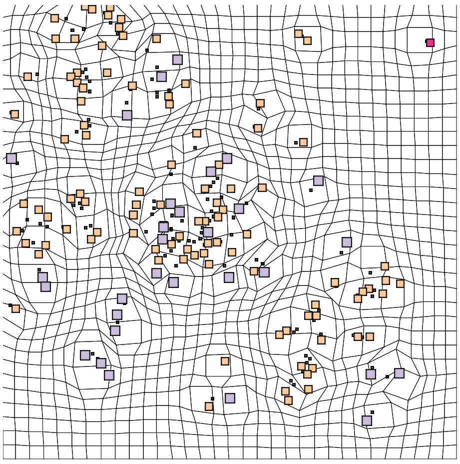


Figure 8.19: The parameterisation of magnification for a cell. The expansion needs to be such that after magnification $d2$ is equal to $d1$ before the magnification.

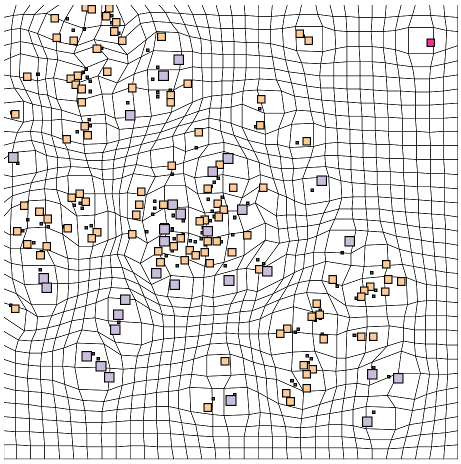
straightforward. Because the grid has been aligned these will either follow the side of a cell or run cross it diagonally. In each case the length of the feature as it crosses the cell is calculated (i.e the length of the cell side or the diagonal) and this is multiplied by the symbol width, or half the symbol width if the feature follows an edge.

Adding expansion values only to the cells where points are found can cause the cells immediately neighbouring to absorb most of the magnification, though they will at least seek to maintain their own areas during the transformation. A better solution is attained when the expansion is distributed more widely. This is achieved by *smoothing* the magnification field over the grid. A simple spatial averaging filter is applied to each cell using a kernel defined by the cells that are directly adjacent to it. Hence in total five cells will contribute to the new value of the cell under consideration. The contributions of neighbouring cells are weighted according to length of the shared boundaries. In addition, the contribution of the central cell is weighted according to a fixed parameter greater than one. Thus the greater the weight of the central cell the more influence it will have on the new value. The filter can be passed over the field a number of times. The more iterations of the filter the more the values will be distributed over the grid. The effects of changing these two parameters (the centre weight and the number of smoothing iterations) is shown with the examples in Figure 8.20.

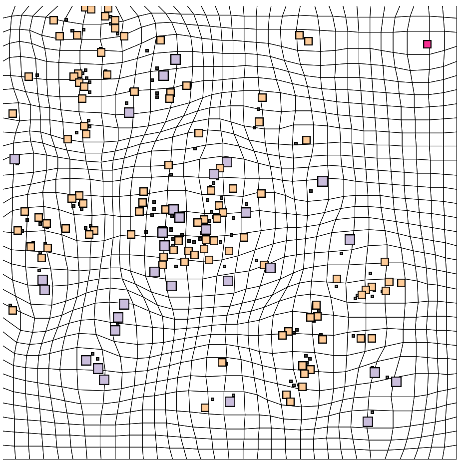
In Figure 8.20 it can be seen that without smoothing there is a tendency for cells where no magnification has been set to be strongly deformed. When either the number of iterations is high or the centre weight is low, the transformation is



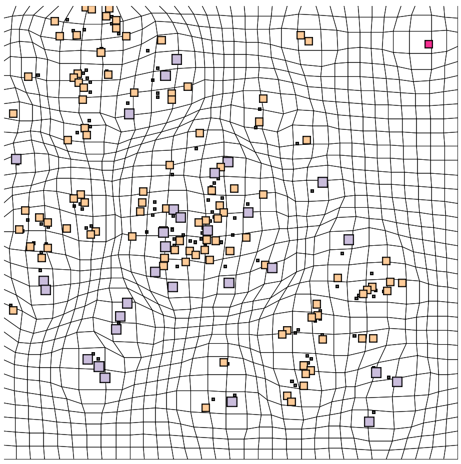
(a) No smoothing



(b) Weight 50, Iterations 1



(c) Weight 50, Iterations 10



(d) Weight 2, Iterations 1

Figure 8.20: The effect of varying smoothing parameters. a) No smoothing is employed. b) Centre weight is high so there is little contribution shared between cells, the number of iterations is low so there is little dispersion of values over the grid. c) Centre weight is high so there is little contribution shared between cells, number of iterations is high so the dispersion is wide. d) Weight is low so there is a lot of contribution of values amongst cells, iterations is low so there is little dispersion.

much more uniform around the features. Conversely when the center weight is high and the number of iterations is low the smoothing is much more localised around clusters of features.

8.2.9 Functional Triangulation Approach

The functional described in Sections 8.2.5 and 8.2.6 is not limited in its application to a grid based data structure. Indeed, in the work on surface parameterisation described previously in Section 8.2.5 almost always the discretisation of space used is a triangulation. In addition, a grid can always be seen as a special form of a triangulation. The method is also implemented here on such a data structure. This has a disadvantage over the grid based methods that it becomes more difficult to separate out the two types of data, background and foreground, and thus allow different types of processing competence to be designated to different points in the MVC architecture. Though it is possible still to create an initial triangulation based on the background features (pinning the nodes of these to constrain the transformation), and then re-mesh the triangulation based on the foreground points-of-interest produced in response to user interaction. A second problem is that it becomes more difficult to locate an arbitrary position within the triangulation and project this according to final transformation, though this can be achieved for instance using barycentric coordinates (c.f Farin, 1990). The main reasons for implementing the technique on a triangulation here are that it compares more closely with existing methods from generalisation research on the displacement of points, for example Ruas (1998); Ware and Jones (1998). These tend to favour object primary methods because they can explicitly evaluate the proximity between features. Figure 8.21 illustrates a triangulation with the nomenclature used here.

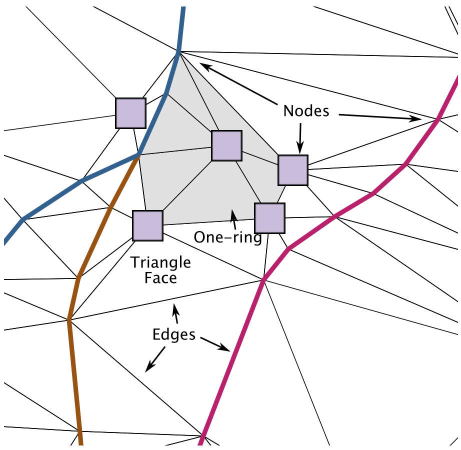


Figure 8.21: Example of a set of triangulated features labelled to show particular terms. The 1-ring of a node is shaded in grey.

There are two main difficulties in moving from the grid case to the triangulation one. The first is that when a triangulation is based solely on the geometry of map features and is therefore irregular, individual triangles will extend over very different sized areas with two objects linked by an edge of the triangulation often being far apart. This causes a problem because the functional will attempt to ensure that the spatial relationships between these are preserved even though they may be so far apart that for the purposes of visualisation the relationship is largely irrelevant, since they lie in different clusters of objects. Ruas (1998), for example, handles this problem by allowing displacement forces to decay accordingly over a defined propagation distance. The second problem is that displacement on a triangulation is more properly formulated in terms of the lengths of edges between features rather than area of triangles. Where a length needs to be greater than a threshold based on the symbol width and minimum separation distance between two points. Particularly when also considering the first problem, this makes the formulation of the functional problematic because it assumes that the edges of data structures being enlarged will stretch equally, whereas the need here is to favour the expansion of triangle areas with respect to particular edges.

To cope with the first issue an approach similar to that described by Ruas (1998) is employed. The amount of expansion that the symbolisation will cause is first computed for each edge. For edges between two points-of-interest this is calculated directly from the symbol width (augmented with a minimum separation distance of 2 pixels) and symbol shape (e.g. a square) and the direction of the edge between the points. For an edge that is between a point-of-interest and a linear feature the expansion is computed by evaluating the smallest distance between the point and its projection onto the feature. This distance is added to the respective symbol sizes is then used to compute how much the edge needs to grow. If the edge length or projection length is less than the combined symbolisations, the target length is taken as it is. If the length is greater than this minimum requirement, it is compared to a constant value that controls propagation. This decays the amount of expansion linearly according to how much less the edge or projection length is compared to the propagation distance. Equation 8.19 describes this,

$$\mathrm{Expansion}_T = \left(1 - \frac{\mathrm{Length}_E - \mathrm{Length}_{Min}}{\mathrm{Length}_{Min} + \mathrm{Length}_{Prop}}\right)(\mathrm{Length}_T - \mathrm{Length}_E) \qquad (8.19)$$

where $\mathrm{Expansion}_T$ is the new expansion for the edge (i.e. this is added to the initial edge length). Length_E is the initial edge or projection length. Length_{Min} is the minimum length an edge or projection needs to separate the symbols, and Length_{Prop} is a constant defining the propagation distance. Length_T is the total target edge length induced by the symbolisation, essentially this is being scaled by the propgation distance. If the initial edge length or projection length is greater than the propagation distance, the edge lengths are set to remain unchanged. During processing these edges will need to absorb the transformation energy, so they are also allowed to shrink up to the propagation distance.

To deal with the second problem, the form in which the area is computed in the functional had to be adapted to allow it to be weighted according to an unequal expansion of edges.

Chapter 9

View: Experiments

In order to evaluate the different approaches proposed a series of quantitative and qualitative tests were performed using a set of five example maps. The examples use two different datasets. The first uses Swisstopo VECTOR25 data for a rural region in Switzerland, Albis and the Thülersee. This consists the road network together with a set of points-of-interest that are individual trees. The second also uses Swisstopo VECTOR25, but is from an urban area (Zürich). It uses the centroids of buildings for points-of-interest together with the major roads. To make patterns more readily visible, the points-of-interest have filtered at random to remove half of the points.

These datasets have been chosen because they provide real world geographic patterns which are on the one hand strongly anthropogenic, in the case of the urban data, and relatively natural in the case of the rural data. Tests are performed using two different point-of-interest symbol sizes, with the symbology being doubled in the second set of tests. The aims of the tests are to consider:

1. The amount of conflicts (overlapping symbology) resolved by the transformations.

2. The quality of displacement in terms of how well spatial relationships are preserved.

3. The effects of increasing the symbol size for points of interest.

4. The effects of increased volume of information.

5. The effects of changing the parameterisation (grid density and amount of smoothing).

The qualitative analysis is performed by observation. It discusses both the overall impressions given by the different approaches and comparisons of particular examples found by identifying small situations of objects, for instance within a partition or forming a clear cluster. This form of analysis is performed for the smaller and larger symbol sizes.

Quantitative analysis is conducted on all samples using summary statistics computed and for one example using more detailed comparative analysis. The summary statistics are computed by counting the number of non-white pixels before and after the transformations, an increase in the number of pixels indicated the amount of displacement that had taken place overall. The detailed analysis is based on a triangulation of the points-of-interest and roads. This is used as an objective basis for measurements that is independent of any particular method. Because the triangulation based transform relaxes the constraint for preserving angles during the course of its operation, basing the evaluation on a triangulation does not bias the results towards this transformation approach. For each point-of-interest, the edges and triangles emanating from it are measured to evaluate the quality of the displacement. The resolution of conflicts can be considered by measuring the lengths of edges with respect to the minimum length they need to obtain to resolve a conflict between a point-of-interest and another point-of-interest, or a point-of-interest and a road. How well the displacements preserve spatial relationships is computed using the MIPS energy is calculated for each triangle before and after the transformations and compared. For both the edge measurements and the triangle measurements t-Test scores are then calculated to compare the results between pairs of transformation methods.

9.1 Results: Regular Symbols

The figures in Tables 9.1-9.5 show the map samples and the effect of the transformations. Each transformed map is shown additionally with the data structure (grid or triangulation) used to discretise the underlying space superimposed.

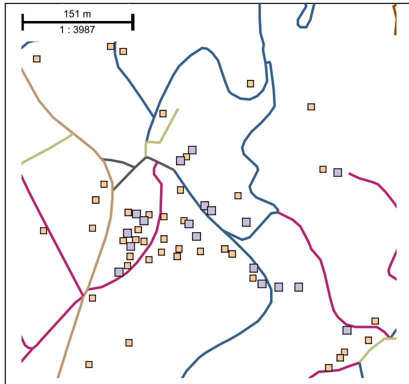
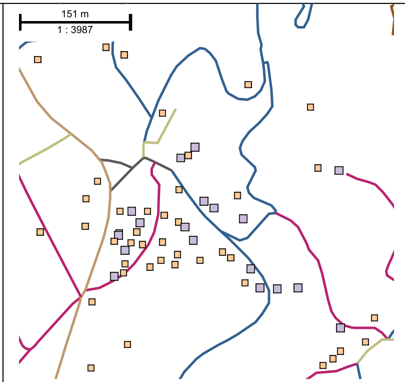
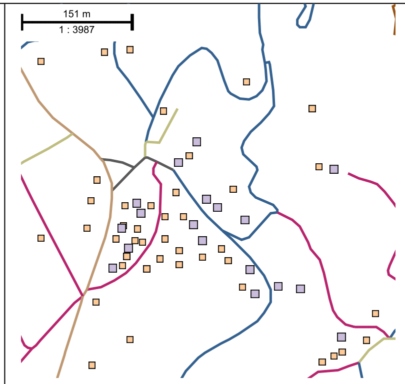
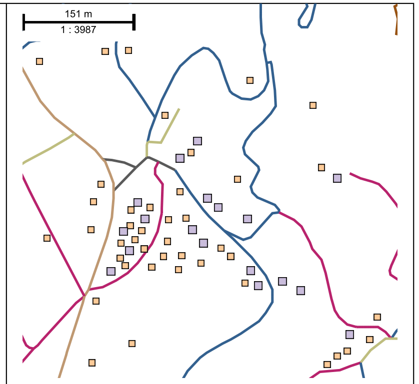
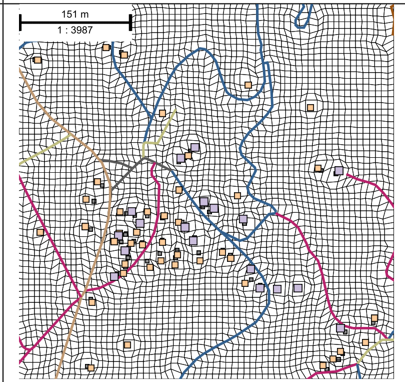
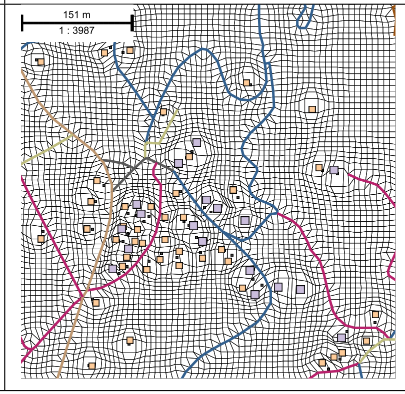
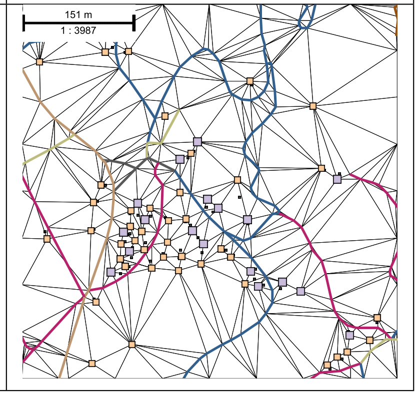
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			
			

Table 9.1: Example 1: Transformation approaches applied to Swisstopo VECTOR25 data for a rural area. The points are data for individual trees. The lower figures show the underlying data structure (i.e. grid or triangulation) being used to discretise the space in its deformed state. The small black marks show the original positions of the features.

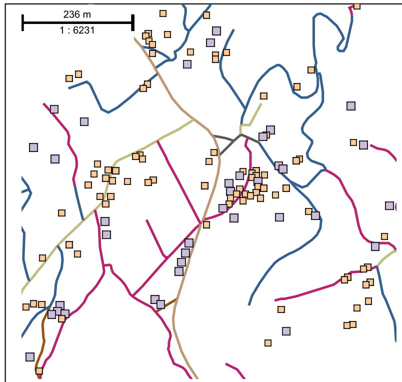
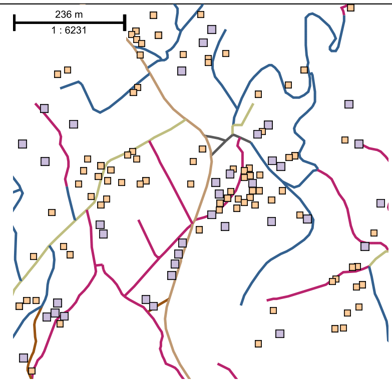
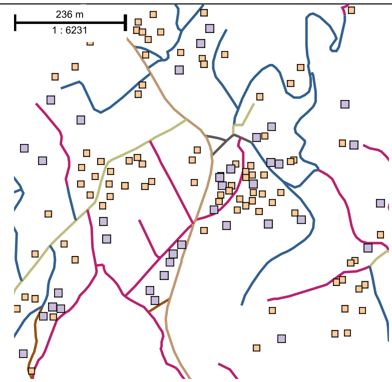
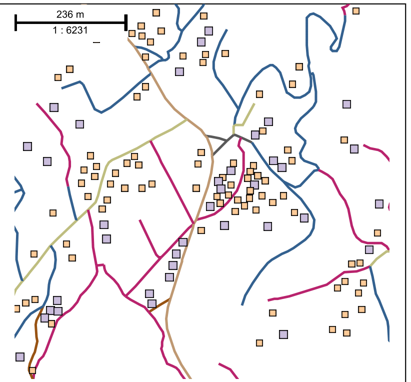
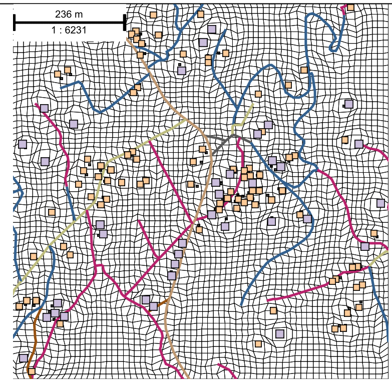
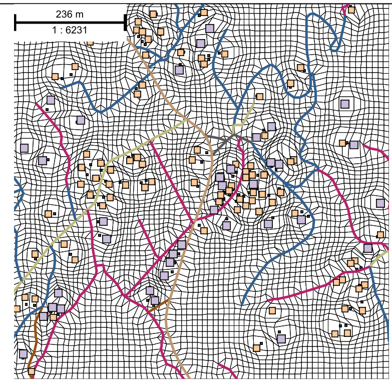
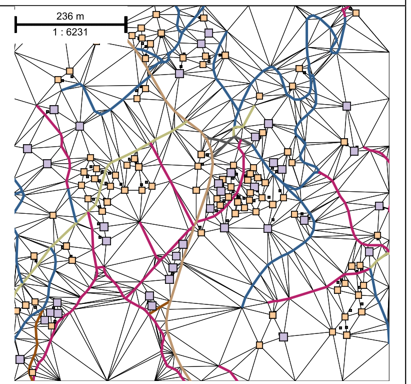
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			
			

Table 9.2: Example 2: Transformation approaches applied to Swisstopo VECTOR25 data for an extended portion of th rural area shown in Table 9.1. The points are data for individual trees. The lower figures show the underlying data structure (i.e. grid or triangulation) being used to discretise the space in its deformed state. The small black marks show the original positions of the features.

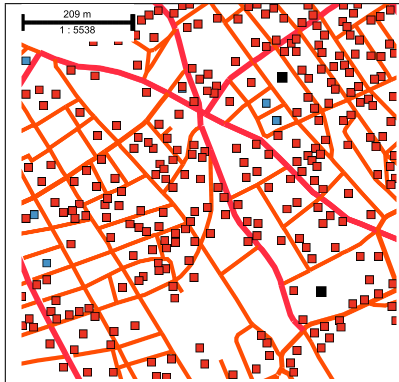
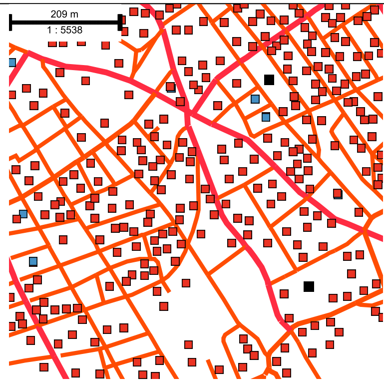
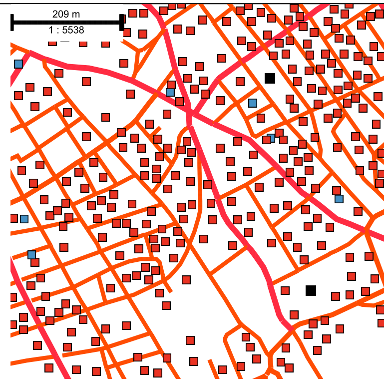
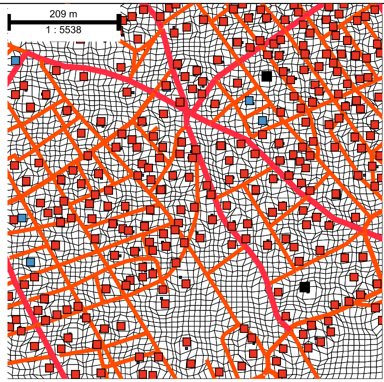
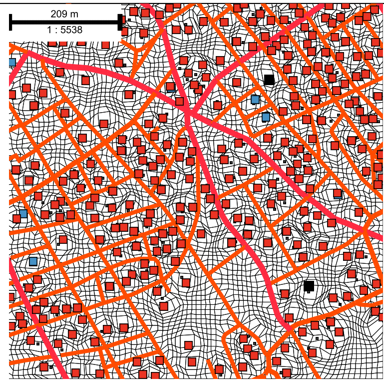
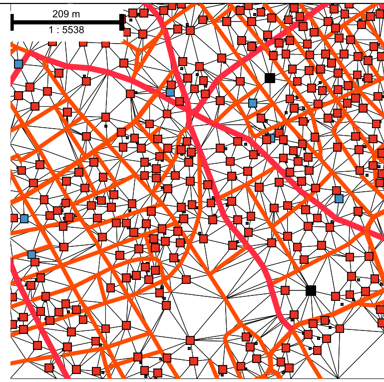
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			
			

Table 9.3: Example 3: Transformation approaches applied to Swisstopo VECTOR25 data for an urban area (Zurich). The points are data derived from the centroids of buildings. A filter has been used to remove half the points at random. The lower figures show the underlying data structure (i.e. grid or triangulation) being used to discretise the space in its deformed state. The small black marks show the original positions of the features.

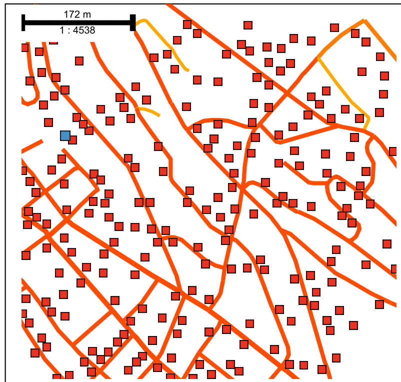
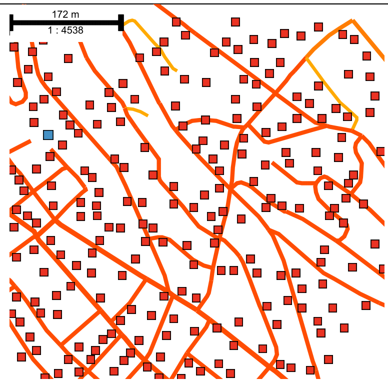
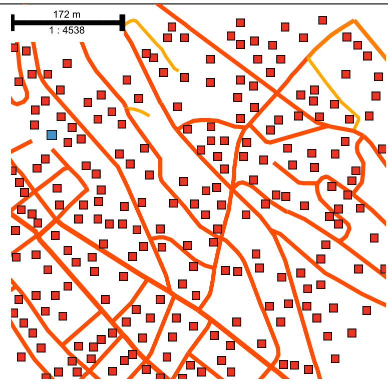
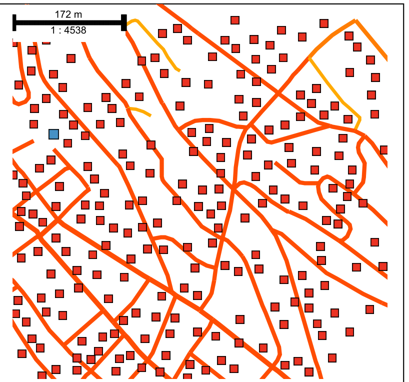
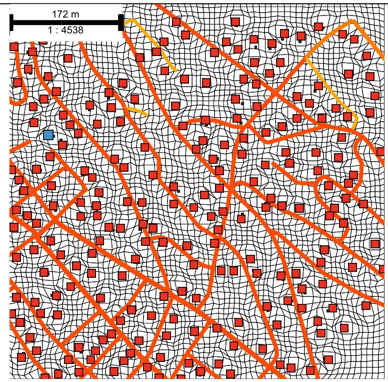
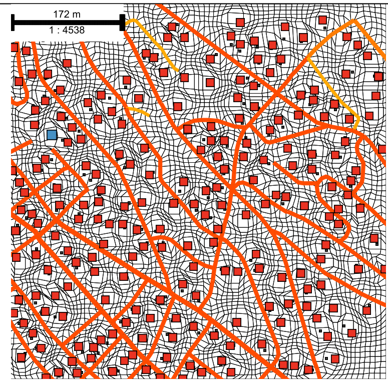
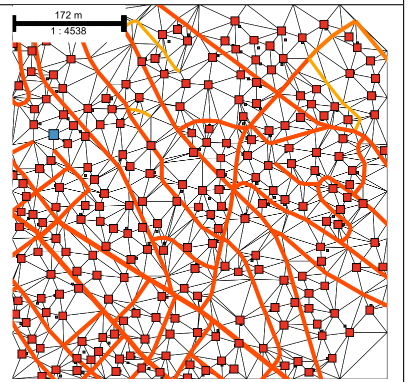
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			
			

Table 9.4: Example 4: Transformation approaches applied to Swisstopo VECTOR25 data for an urban area (Zurich). The points are data derived from the centroids of buildings. A filter has been used to remove half the points at random. The lower figures show the underlying data structure (i.e. grid or triangulation) being used to discretise the space in its deformed state. The small black marks show the original positions of the features.

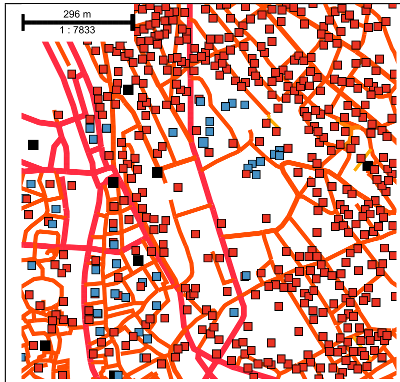
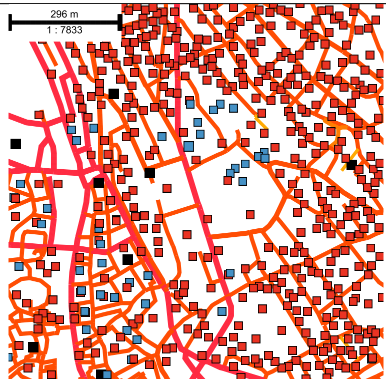
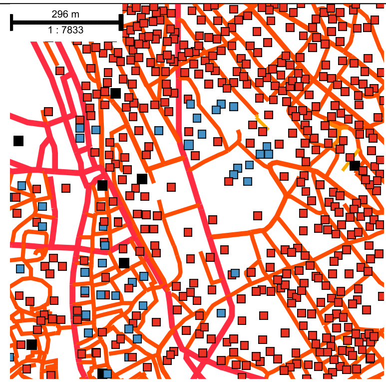
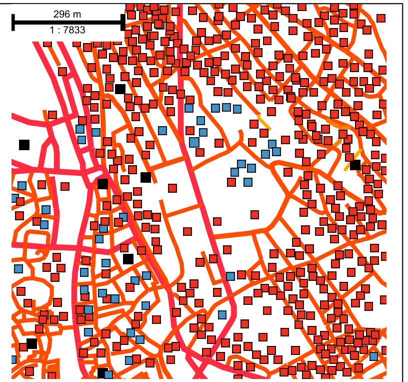
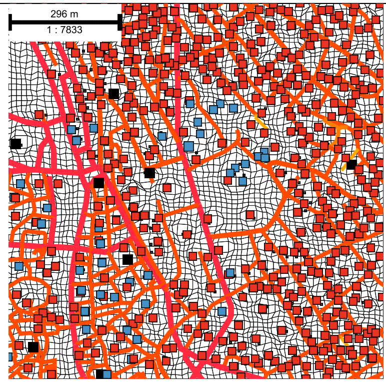
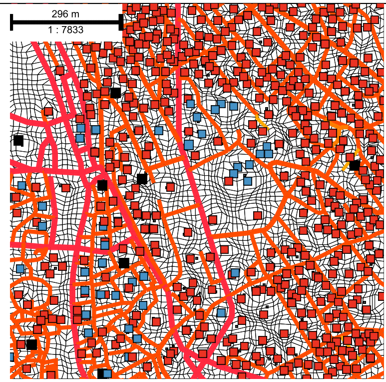
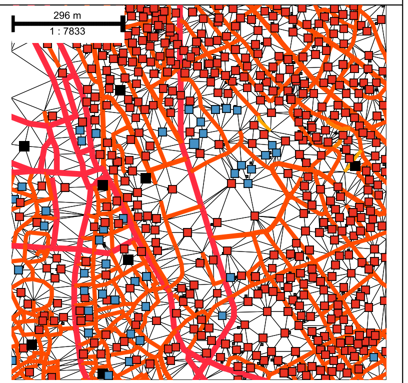
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			
			

Table 9.5: Example 5: Transformation approaches applied to Swisstopo VECTOR25 data for an urban area (Zurich). The points are data derived from the centroids of buildings. A filter has been used to remove half the points at random. The lower figures show the underlying data structure (i.e. grid or triangulation) being used to discretise the space in its deformed state. The small black marks show the original positions of the features.

9.1.1 Observations: Map Example 1

This example (Table 9.1) uses a rural area with a relatively low density of information and comparatively small symbols. There is an overall impression of separation amongst the points in all of the three methods, though this is most distinct for the two functional based approaches. The lack of a strong constraint to fix the data structure to the road network is clearly visible in the KT-grid, where a number of points can be seen pushed against roads as the grid tends towards areas of lower density. The separation is clearest for the triangulation, which is understandable because it is defined amongst objects, though in some instances here the impression of density is lost, implying that the method is better for resolving conflicts than preserving spatial relations.

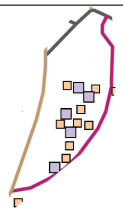
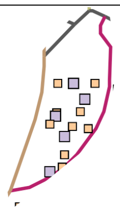
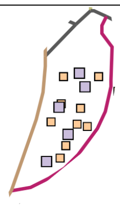
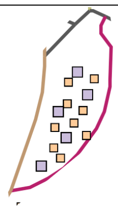
Untransformed	**KT-grid**	**Functional Grid**	**Functional Triangulation**
			

Table 9.6: Inset of the central partition in Example 1 (Table 9.1)

Table 9.6 focuses in on the central partition of Example 1 where the information is densest. An immediate observation here is that one of the points in the untransformed image is completely covered by another point. Neither of the grid methods are able to satisfactorily separate these points because they are lying too close to each other. Though they do manage to make the point at least apparent. The triangulation based method on the other hand is able to separate these two points because it can directly enlarge the edge between them. A second observation is based on the number of clusters that appear after the transformations. The functional grid approach visually separates out three clusters of points, one at the top, a large one to the right and a small one to the left. Largely this is due to the group being stretched out along the contour of the partition. The KT-grid approach is similar though less well defined, because the energy in the grid is able towards the bottom of the partition and which is being dispersed outside it, due to the lack of a constraint fixing the transformation along the roads. In the triangulation method only a single compact group is discernible, implying it favours the solution of conflicts over the preservation of spatial relations.

Table 9.7 focuses on the centre of Example 1. One of the clearest observations is that the triangulation method tends to cause more spreading than the others resulting in a more uniform pattern, though in addition it is in general better at separating the points from the road network. The KT-grid approach actually probably provides the best result here. Part of the reason for this in comparison to the

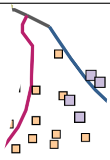
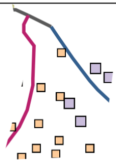
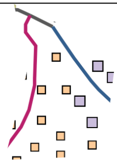
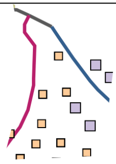
Untransformed	**KT-grid**	**Functional Grid**	**Functional Triangulation**
			

Table 9.7: Inset from the center of Example 1 (Table 9.1)

functional grid, is that although the overall separation is less the deformation is spread more regularly and over a wider area (as show by referring to the grid in Table 9.1). A similar effect could be achieved by increasing the amount of smoothing of the functional grid, which is discussed later. The main problem with doing this is that it loses some of the definition of clusters locally, that is it means the method has a less local *support*.

Untransformed	**KT-grid**	**Functional Grid**	**Functional Triangulation**
			

Table 9.8: Inset of an alignment of point from Example 1 (Table 9.1)

Table 9.8 shows an alignment of three points perpendicular to a road. All methods are able to separate the points. Though in the case of the functional grid this separation is really too great for the uppermost point. The reason for this will be due to the particular positioning of the point within a cell, where the further it is from the centre the more displacement it will experience.

9.1.2 Observations: Map Example 2

Example 2 (Table 9.2) covers the same area as Example 1, which can be seen in the centre. Amongst the interesting features of this example are the relationships between the roads and the points-of-interest as well as particularly regular arrangements of objects. In all cases there is a reasonable separation between the points and the road network, though again in the KT-grid this is limited by the lack of a pinning constraint. Apart from that the overall solutions are fairly similar.

Table 9.9 focuses in on the same region as is covered in Table 9.1. The results of the two grid approaches are similar, though the functional method is better able to move the points away from the roads, if only barely sufficiently. The triangulation is much better at separating the features from the roads. Within the partition on

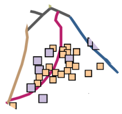
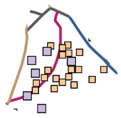
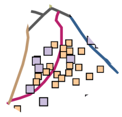
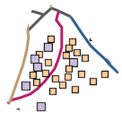
Untransformed	**KT-grid**	**Functional Grid**	**Functional Triangulation**
			

Table 9.9: Inset from the centre of Example 2 (Table 9.2)

the left it also preserves the spatial relationships quite well, though outside this partition these are not as well maintained as in the other methods.

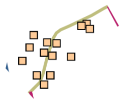
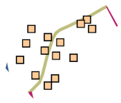
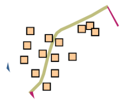
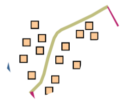
Untransformed	**KT-grid**	**Functional Grid**	**Functional Triangulation**
			

Table 9.10: Inset from the centre-left of Example 2 (Table 9.2)

Table 9.10 considers a regular arrangement of points surrounding a road. The two grid based approaches have similar results maintaining the overall patterns reasonably well. The regular pattern in the bottom left corner is perhaps too regular in the functional grid approach. This is because the narrow strip of space running between the points here is being constricted by the enlargement of the space between the two groups. This could be reduced by increasing the amount of smoothing so that the cells without points are magnified to a greater degree. Again, the triangulation does the best a separating the points but is poorer at preserving the spatial relationships.

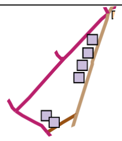
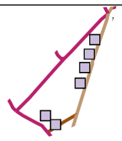
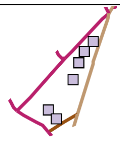
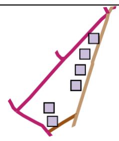
Untransformed	**KT-grid**	**Functional Grid**	**Functional Triangulation**
			

Table 9.11: Inset from the centre-bottom of Example 2 (Table 9.2)

Table 9.11 considers a line of points within a sharp partition. The KT-grid and the triangulation based approaches are best able to preserve the spatial relationships here, whereas the functional grid approach seems to get trapped at the top of the partition. The KT-grid is better able to deal with the situation because the fact that it is not fixed means that it can spread out more uniformly while the functional grid cells at the top of the position are not able to grow. Of course, because it is not fixed the KT-grid is not able to separate the points from the road, whilst the functional grid does attempt to achieve this. The triangulation gives the best result though does poorly in preserving the relationships between the two points at the bottom of the partition.

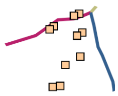
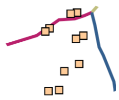
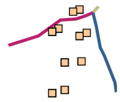
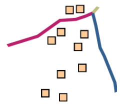
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			

Table 9.12: Inset from the lower-right corner of Example 2 (Table 9.2)

Table 9.12 illustrates a situation where some points are very close to a road. Only the triangulation is able to displace these reasonably. For the functional grid it is clear from looking at the grid (Table 9.2) that part of the reason for this is that the functional has not been restricted to only consider the situation on the side of the road where the point lies, hence most of the growth of the cell ends up taking place on the other side of the road, this is clearly undesirable and in need of correction.

9.1.3 Observations: Map Example 3

Example 3 (Table 9.3) shows an urban area. The main characteristics are that the points are confined to many small partitions which limits their movement much more than the partition did meaning the solutions are highly constrained with little room for variation in the energies generated by the symbology. Example 3 shows an area that is reasonably dense, though without so much conflict. The overall impression is that all solutions achieve a fair degree of separation but are not so different.

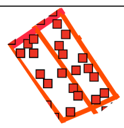
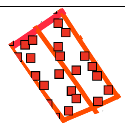
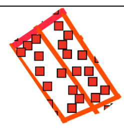
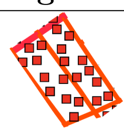
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			

Table 9.13: Inset from the top-right corner of Example 3 (Table 9.3)

Table 9.13 shows two partitions from the top-right corner of Example 3, which is where the information is densest in this example. The functional grid provides the best result in this instance, both in terms of spatial relations and separation.

This contrasts with the KT-grid method whose result is barely different from the original. The reason for this that that the support in this method is less local than for the functional grid, hence the transformation is less able to find area which it can constrict since the space is so limited. The more localised support of the functional is able to vary distribution of the space much better. The triangulation is for the most part able to separate the points though the relationships are not so well preserved. Examination of the data structure in Table 9.3 indicates however that where it has been unable to separate the points is because the triangulation has failed to conform to the central edge, which is an flaw in the building of the data structure rather than because of the method itself.

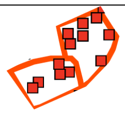
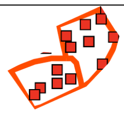
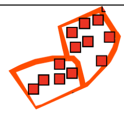
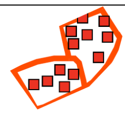
Untransformed	**KT-grid**	**Functional Grid**	**Functional Triangulation**
			

Table 9.14: Inset from the centre-left of Example 3. (Table 9.3)

Table 9.14 shows two partitions from a less dense region of the map. The functional grid approach again shows the best result. The triangulation is interesting because it is apparent that it is attempting to find a solution that is the most uniform given the available space, though again the data structure appears to have failed to conform with the edges of the road network.

9.1.4 Observations: Map Example 4

Example 4 (Table 9.4) shows a less dense region of urban area than Example 3 did, with larger road partitions and fewer buildings. The overall impression is that all the methods have achieved a separation, though this is best for the two functional based methods.

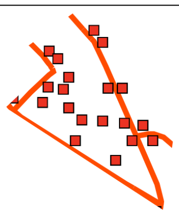
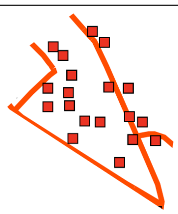
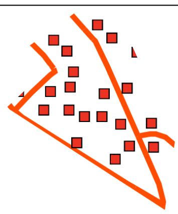
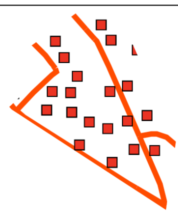
Untransformed	**KT-grid**	**Functional Grid**	**Functional Triangulation**
			

Table 9.15: Inset from the left side of Example 4 (Table 9.4)

Table 9.15 shows an open partition from the left side of the map. The two methods based on the functional perform the best and give quite similar results.

The KT-grid method is poor though again this is likely because of the lack of a pinning constraint on the mesh which causes points to be pushed onto or over the road network.

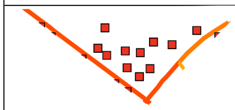
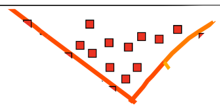
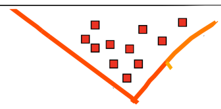
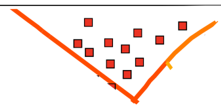
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			

Table 9.16: Inset from the centre top side of Example 4 (Table 9.4)

Table 9.16 shows an open partition at the top of Example 4. The main interest of this example is to consider the treatment of spatial relationships. The best result is obtained by the KT-grid method, which achieves a good balance between the separation and spatial relationships. Considering the data structures shown in Table 9.4, the result is better than the functional because of the wider support that the technique has. This causes the cells to grow in a more uniform way. The smaller support of the functional hinders it because the points are sufficiently spaced that few cells lying between them are absorbing most of the expansion which results in a more uneven spreading overall.

9.1.5 Observations: Map Example 5

Example 5 (Table 9.4)shows a very dense region of the urban area containing both many points and many small partitions. The main impression given by this example is that no solution performs well if the density of information is too high and hence that other more aggressive pre-selection filters need to be applied before attempting the displacement (c.f. de Berg et al., 2004). In spite of this, it is apparent that a reasonable degree of separation has been achieved in each case and that individual points are for the most part recognisable.

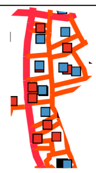
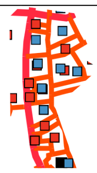
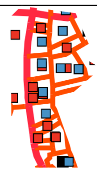
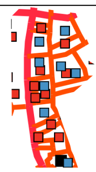
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			

Table 9.17: Inset from the bottom left of Example 5 (Table 9.5)

Table 9.17 shows a region of very small partitions constraining the points. Only the triangulation obtains a reasonable result here. For the grid methods either the partition size is too small relative to the grid width to allow enough deformation of the space or points are too close together for the deformation to have a sufficient effect.

9.1.6 Analysis of Pixel Counts

Table 9.18 describes the percentage change in non-white space in the different map examples. The statistic is computed by counting the number of white pixels and subtracting this value from the the total number of pixels to give the number of non-white pixels. The percentage change with respect to the non-white pixels of the untransformed map is then taken. The value indicates how much the transformations have caused overlapping symbols to be separated. Since when two symbols are overlapping they will occupy the same space the value will increase as conflicts are resolved.

Example	**KT-grid**	**Functional Grid**	**Functional Triangulation**
1	0.747	1.546	1.520
2	2.574	4.786	5.500
3	-0.589	2.176	2.384
4	0.171	2.623	1.764
5	0.981	4.013	5.506

Table 9.18: Comparison of methods by analysis of pixel counts. Values show the percentage change in numbers of non-white pixels after the transformations.

It can be clearly seen in Table 9.18 that the KT-grid consistently produces the worst results. From the observations it would seem that there are two main reasons for this. First is the lack of a constraint that fixes the mesh along the network. This is most likely the cause of the negative value for Example 3, since points have been pushed onto the roads which has decreased the number of non-white pixels. Secondly, the amount of magnification is usually smaller locally but covers a wider area than for the functional grid where the support is very localised around the points. This situation could be improved by increasing the magnification values by a scaling factor, though this would also increase the size of the support. The functional based methods are fairly similar though the triangulation appears to do slightly better. This is matched by the qualitative observations where for the most part the triangulation achieves a better separation.

9.1.7 Analysis of Edge Lengths

Analysis of edge lengths is performed for Example 2 (Figure 9.2), the results are shown in Table 9.19. For every point of interest the edges emanating from it where measured and recorded, hence some edges are duplicated in the calculation, i.e.

where an edge connects to another point of interest. Solved situations are where an edge was too small to begin with but reached its minimum threshold after the transformation. To reach the threshold the edge needs to be longer than the two symbol sizes (with respect to the direction of the edge) and a minimum separation distance of 2 pixels (with respect to the map scale). Improved situations are where the minimum threshold has not been reached but the edge length has increased. Worsened situations are where the final edge lengths are not at the minimum threshold and their lengths are shorter than their length was to begin with. New conflicts are a special case of worsened conflict where the original edge was already at its threshold. Because the worsened situation include the new conflicts the total does not include these. Worsened cases maybe caused in a number of ways. In the KT-grid case the most obvious is a point being pushed onto a road. For the other methods they are most commonly caused by the road symbology squeezing points within a partition together or the point being pushed apart by each other, then coming into conflict with the roads.

Type of situation	**KT-grid**	**Functional Grid**	**Functional Triangulation**
Solved	79	127	157
Improved	67	30	14
Worsened	75	46	37
New	17	3	4
Total	221	207	208

Table 9.19: A comparison of the method's abilities to resolve conflicts for Example 2. The worsened values also include the new conflicts.

Table 9.19 indicates that the triangulation performed best solving around 75% of the conflicts and improving (solved and improved) 82% of them. The functional grid faired less well, solving around 61% and improving around 76% of them. The grid performance was the lowest, only solving around 36% and improving 66%. The relative performance compares similarly to the results of Table 9.18 for pixel accounts. Based on the qualitative analysis these results can be seen as somewhat over-critical, given the worsened cases which for the two functional cases are fairly hard to spot in the graphical results of Table 9.2.

Statistical comparisons between the different methods are made in Table 9.20. Here the lengths that edges need to grow to after the transformation are compared between pairs of approaches. The ideal value is zero meaning that the lower the mean the better the result will be. Values in the table are t-Test scores between pairs, with variable one of the computation in the rows and variable 2 in the columns. A negative value indicates that the mean was lower for the first variable than the second, in absolute terms the matrix is symmetric.

The results of the t-Test indicate that at the .05 threshold, given by the critical

	KT-grid	Functional Grid	Functional Triangulation
KT-grid	-	4.9970	7.0975
Functional Grid	-4.9970	-	3.2271
Functional Triangulation	-7.0975	-3.2271	-
Observations = 797		t Value (two-tail) = 1.96295 (p = .05)	
$\bar{X}$	3.1365	1.9266	1.2206
σ^2	52.7437	36.5260	25.2757

Table 9.20: Statistical comparison between the different approaches using a t-Test. The analysis compares the amount that edge lengths still need to grow to completely solve a conflict for Example 2. In the ideal case these would all be zero, hence the lower the mean the better the result.

value in the table, the triangulation method has been significantly better than the other methods in resolving the conflicts of Example 2, and that the functional grid has been significantly better than the KT-grid approach. This concurs with the observations and the other quantitative analyses.

9.1.8 Analysis of Spatial Relationships

The distortion of shape is evaluated using the MIPS energy. This is computed between pairs of edges constituting a triangle emanating from a point of interest. Because the MIPS energy is not a single energy for the whole triangle, but rather varies at each point of the triangle in relation to the original triangle at that point, values are not duplicated.

Table 9.21 compares the values for the MIPS energy in a similar way to that which was used for comparing the conflict resolution. The MIPS energy here takes a value of one when it is at its minimum, and a positive value otherwise. Since none of the results exceed the critical value no significance can be given to the results. This is not entirely surprising, since it is to be expected that the results are fairly similar. However, one reason for the lack of statistical significance can be is because the measure is too global. Since of greatest interest here are the situations where points are in close proximity the smallest triangles (25 percentile after the triangles are ranked by area) are considered independently. Table 9.22 describes the result. The result in Table 9.22 shows that the functional grid is significantly different to the others. Since the mean is lower it can be inferred that it is better in terms of the preservation of spatial relationships. This concurs with many of the observations previously made.

	KT-grid	Functional Grid	Functional Triangulation
KT-grid	-	0.1787	-1.4882
Functional Grid	-0.1787	-	1.6485
Functional Triangulation	1.4882	1.6485	-
Observations = 797		t Value (two-tail) = 1.96295 (p = .05)	
$\bar{X}$	1.5022	1.4786	1.8616
σ^2	9.6435	4.5833	38.1640

Table 9.21: Statistical comparison between the different approaches using a t-Test. The analysis compares the MIPS energy after the transformation for Example 2. In the ideal case these would all be one, hence the lower the mean the better the result.

	KT-grid	Functional Grid	Functional Triangulation
KT-grid	-	2.1220	1.7157
Functional Grid	-2.1220	-	-2.3161
Functional Triangulation	-1.7157	2.3161	-
Observations = 200		t Value (two-tail) = 1.97196 (p = .05)	
$\bar{X}$	2.2294	1.4065	1.5681
σ^2	29.5464	0.6307	0.7351

Table 9.22: Statistical comparison between the different approaches using a t-Test. The analysis compares the MIPS energy after the transformation for Example 2 focusing on the smallest (25 percentile of area) triangles. In the ideal case these would all be one, hence the lower the mean the better the result.

9.2 Results: Enlarged Symbols

The experiments were repeated for Examples 1-4 using symbols that where twice as large (between 16 and 20 pixels). Example 5 was omitted since it was so dense for the regular sized symbols. Tables 9.23 and 9.24 depict the results. This time the data structures have been omitted.

The enlargement of the symbols means that for the most part there is no longer enough space to position symbols in a way that would achieve the desirable separation. The main focus of the discussion is therefore on the different transformation's abilities to separate the symbols sufficiently that they can be seen, whilst accepting a degree of overlap, and that the relationships between points and roads are ensured.

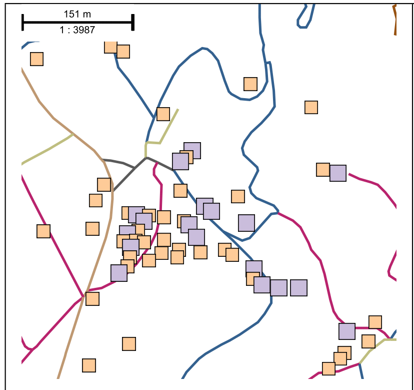
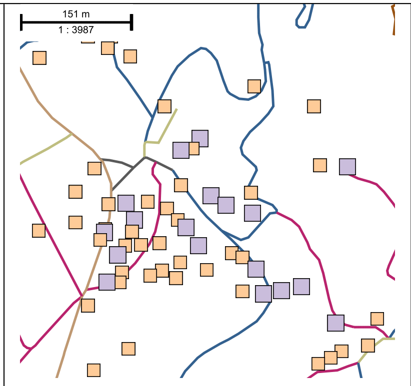
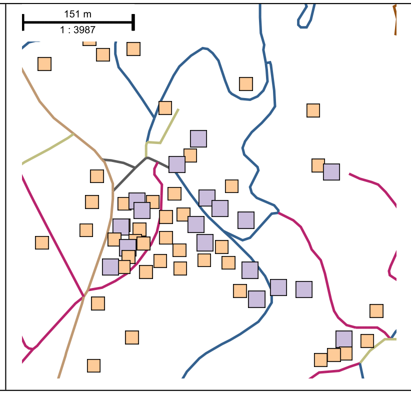
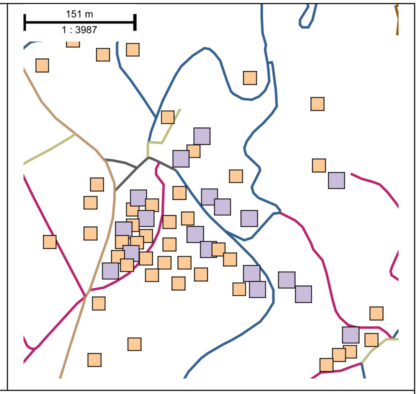
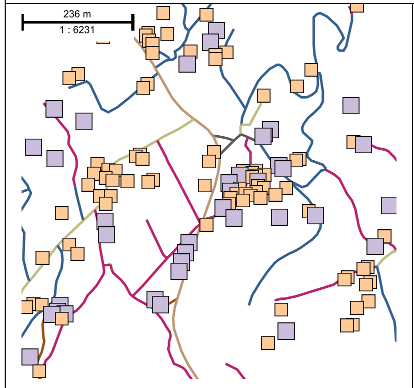
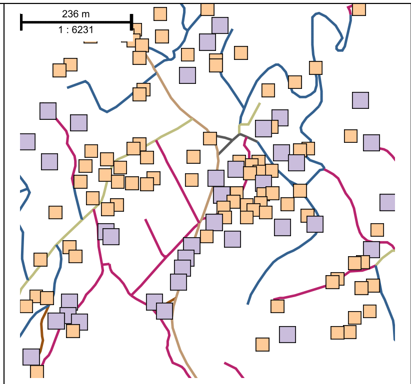
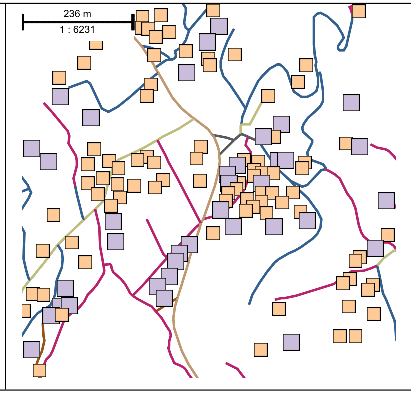
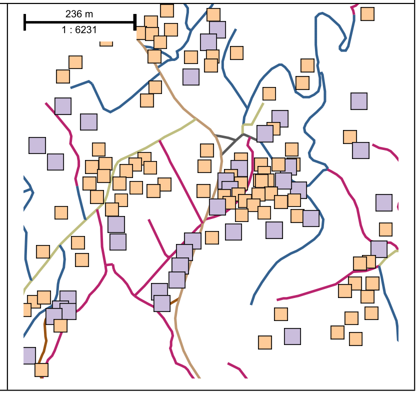
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			
			

Table 9.23: Examples 1 (top) and 2 (bottom) with enlarged symbols.Transformation approaches applied to Swisstopo VECTOR25 data for a rural area. The points are data for trees, symbol sizes range between 16 and 20 pixels.

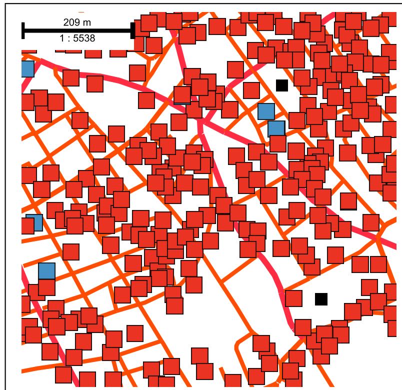
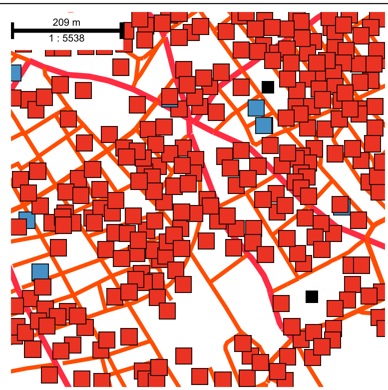
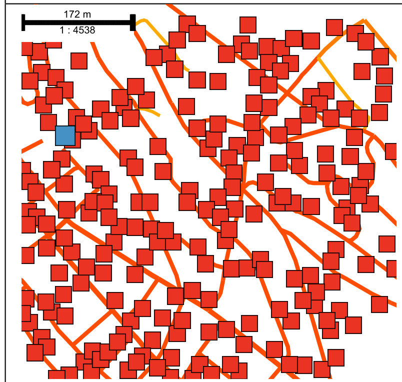
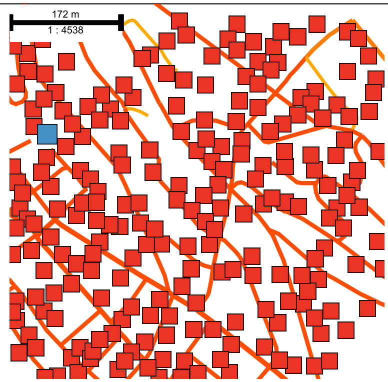
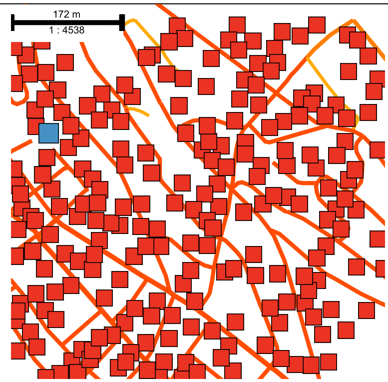
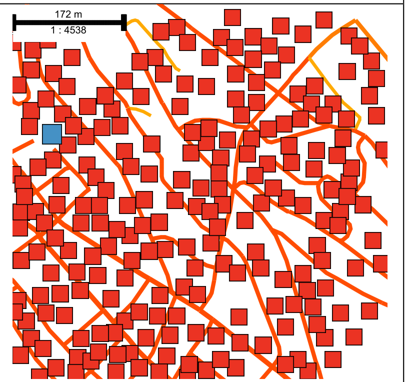
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			
			

Table 9.24: Examples 3 (top) and 4 (bottom) with enlarged symbols. Transformation approaches applied to Swisstopo VECTOR25 data for an urban area (Zurich). The points are derived from building centroids, symbol sizes range between 16 and 20 pixels.

9.2.1 Observations: Map Example 1

The first example (Table 9.23 top) shows quite strong differences between the KT-grid approach and the two functional ones. What is clear is that the increased energy due to the enlarged symbolisation is causing the points to overlap with roads with a fairly high frequency. In spite of this the result is not too bad, although the pattern is quite clearly different from the other methods. For the functional cases the effects of the road network topology has quite marked effects on the nature of the solutions produced which tend to much more uniform distributions within the available spaces.

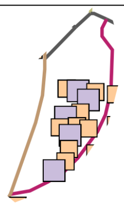
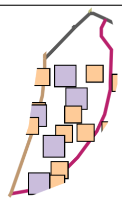
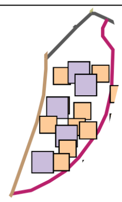
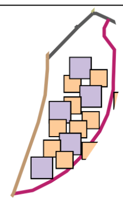
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			

Table 9.25: Inset of the central partition in Example 1 where symbol sizes have been enlarged (Top figures in Table 9.23)

Table 9.25 focuses again on the the central partition of Example 1 where the point information is densest. It is clear that the KT-grid has performed less well than the other approaches, even though the majority of points are now separated. The functional grid approach has not achieved as much separation as the triangulation approach, but the separation is probably sufficient to allow all but one of the points to be discerned and interaction with the points to be enabled (for example with hyper-links). The triangulation whilst achieving a good separation loses most of the sense of varying density amongst groups of points.

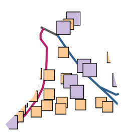
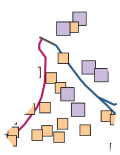
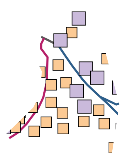
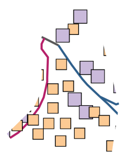
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			

Table 9.26: Inset of the centre region of Example 1 (top figures in Table 9.23) where symbol sizes have been enlarged

Table 9.26 focuses on the open partition to the right of the previous example. The result for the KT-grid here is not as bad as before, and it has at least preserved the impression of relationships amongst the points to some extent. One notable aspect is that it has managed to maintain a crescent of white space around the centre of the cluster of points which is also evident in the untransformed points, particularly in Table 9.1 where the symbols are smaller. In the other cases this region has been lost, at least for the functional grid this is due to the different sizes of support across the grids which is causing this space to be constricted for the functional and magnified for the other grid method. The results for the two functional based techniques are very similar, with the grid approach probably giving the better of the two.

9.2.2 Observations: Map Example 2

Example 2 (Table 9.23 bottom) shows a rural situation where the symbol size is both enlarged and the volume of information high. The results are all reasonably similar with the amount of separation substantially improving the visibility of individual points.

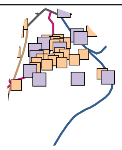
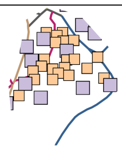
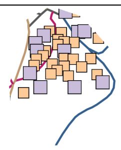
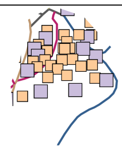
Untransformed	**KT-grid**	**Functional Grid**	**Functional Triangulation**
			

Table 9.27: Inset of the centre region of Example 2 where symbol sizes have been enlarged (bottom figures in Table 9.23)

The inset in Table 9.27 shows the area in the centre of the map where the volume of points is at its densest. In comparison to the starting state all the methods have achieved a reasonable result, though it is again clear that the KT-grid is less constrained than the others.

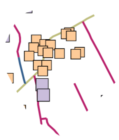
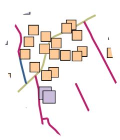
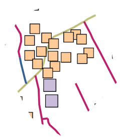
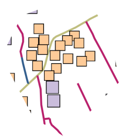
Untransformed	**KT-grid**	**Functional Grid**	**Functional Triangulation**
			

Table 9.28: Inset from the centre-left region of Example 2 where symbol sizes have been enlarged (bottom figures in Table 9.23)

Table 9.28 shows the effect on a more regularly arranged grouping of object. The result is interesting because each solution is fairly dissimilar. The KT-grid has best maintained the arrangement in the top partition though less so in the lower one. The functional grid has also performed reasonably well here. The triangulation on the other hand has found a solution that uses up the available space as best as possible but at the cost of the spatial relationships within this arrangement.

9.2.3 Observations: Map Example 3

Example 3 (Table 9.24 top) shows an urban region, it is really too dense to look at in any detail. The main observation of interest is to notice the different ways in which the areas of high densities of points have been spread. This is most clear for the triangulation, for example in the top right-hand corner, where almost all the available space is taken up by the solution.

9.2.4 Observations: Map Example 4

Example 4 (Table 9.24 bottom) depicts a less dense region of urban area, though the density is still high and dispersed more evenly. The overall impression is that the two grid methods have produced quite similar results. The triangulation is perhaps the most interesting because its propensity for making the end distributions very uniform can quite clearly be seen.

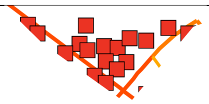
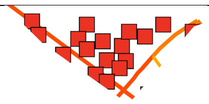
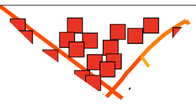
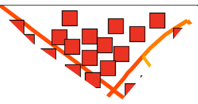
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			

Table 9.29: Inset from the top of Example 4 where symbol sizes have been enlarged (bottom figures in Table 9.24)

Table 9.29 shows quite starkly how the triangulation has favoured solving the separation over preserving spatial relationships, with points almost equally spaced. The grid methods on the other hand have produced almost identical results.

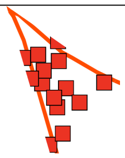
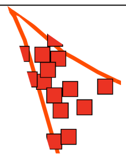
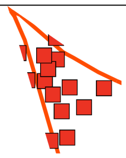
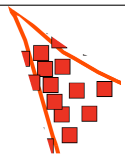
Untransformed	KT-grid	Functional Grid	Functional Triangulation
			

Table 9.30: Inset from the lower right-hand corner of Example 4 where symbol sizes have been enlarged (bottom figures in Table 9.24)

A similar result is shown by Table 9.30 where the grid methods have had difficulty to achieve a separation whilst the triangulation has ended up lining the points fairly evenly along the road.

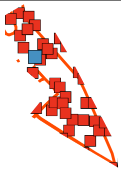
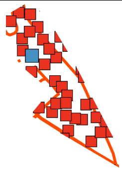
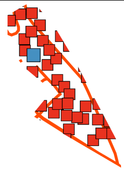
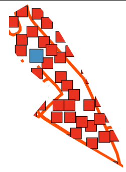
Untransformed	**KT-grid**	**Functional Grid**	**Functional Triangulation**
			

Table 9.31: Inset for the region to the left of the centre Example 4 where symbol sizes have been enlarged (bottom figures in Table 9.24)

Again in the inset shown in Table 9.31, the grid approaches have achieved solutions that are fairly similar and more in keeping with the original pattern, whereas the triangulation is quite different favouring a more uniform distribution that optimises placement according to the available space.

9.2.5 Analysis of Edge Lengths

Analysis of displacement is conducted in a similar way as was done for the regular sized symbols. Table 9.32 describes a comparison of the different situations (solved, improved, worsened, and new) for Example 2 (Table 9.23 bottom). As before, the

Type of situation	**KT-grid**	**Functional Grid**	**Functional Triangulation**
Solved	138	144	194
Improved	104	91	52
Worsened	124	121	96
New	32	26	8
Total	366	360	342

Table 9.32: A comparison of the method's abilities to solve conflicts when the symbol size of the points has been doubled in size (16-20 pixels) for Example 2.

triangulation achieves the best results, with the functional grid method performing slightly better this time. The result for the KT-grid is difficult to compare since the relationships with the road network were so often violated, meaning that while the minimum edge may have been achieved it is only because the point has been moved over a road. Overall though the result agrees with the observations. Again, caution needs to be taken interpreting the worsened cases. A point being moved into a position that is visually an improvement can generate many new or worsened conflicts according to the measure used here. For example if the point-of-interest is within a small partition but pressed against an edge moving it to a visually more satisfactory position may also cause it to be in a worse conflict with the other edges of the partition than it was to start with.

	KT-grid	**Functional Grid**	**Functional Triangulation**
KT-grid	-	-0.3834	4.3547
Functional Grid	0.3834	-	4.9811
Functional Triangulation	-4.3547	-4.9811	-
Observations = 797		t Value (two-tail) = 1.96295 ($p = .05$)	
$\bar{X}$	8.7954	8.9886	6.4008
σ^2	230.1854	248.6661	202.5813

Table 9.33: Statistical comparison between the different approaches using a t-Test. The analysis compares the amount that edge lengths still need to grow to completely solve a conflict for Example 2. The symbol sizes of points have been doubled (16-20 pixels) in comparison to previously. In the ideal case these amounts would all be zero, hence the lower the mean the better the result.

Table 9.33 describes the test for statistical significance amongst the different methods. Here the triangulation based method can be seen to be significantly better than the grid based methods. No such relationship can be inferred between the two grid methods.

9.2.6 Analysis of Spatial Relationships

Tables 9.34 and 9.35 describe the analysis of MIPS energies performed between pairs of approaches at both the 100 and 25 percentiles. There is some suggestion from the mean and variance that the functional grid performs better at preserving spatial relationships than the other approaches which would be in keeping with the observations, but since the t-values fail to reach the critical threshold the results can not be described as significantly different. At least as far as the KT-grid is concerned, one reason for this is that the measure is not stable when the underlying triangulation it is based on becomes degenerate. Since it is built on both the roads and the points, a point crossing the road would cause a triangle to flip and a spurious value for the energy would be computed.

	KT-grid	**Functional Grid**	**Functional Triangulation**
KT-grid	-	1.5115	0.9236
Functional Grid	-1.5115	-	-1.5659
Functional Triangulation	-0.9236	1.5659	-
Observations = 797		t Value (two-tail) = 1.96295 (p = .05)	
$\bar{X}$	4.9314	2.0322	3.0738
σ^2	2905.9426	31.9902	325.4721

Table 9.34: Statistical comparison between the different approaches using a t-Test. The analysis compares the MIPS energy after the transformation for Example 2. The symbol sizes of points have been doubled (16-20 pixels) in comparison to previously. In the ideal case these would all be one, hence the lower the mean the better the result.

	KT-grid	**Functional Grid**	**Functional Triangulation**
KT-grid	-	1.3641	1.0752
Functional Grid	-1.3641	-	-1.2976
Functional Triangulation	-1.0752	1.2976	-
Observations = 200		t Value (two-tail) = 1.97196 (p = .05)	
$\bar{X}$	11.8953	1.6833	3.6624
σ^2	11219.0235	2.0229	462.6231

Table 9.35: Statistical comparison between the different approaches using a t-Test. The analysis compares the MIPS energy after the transformation for Example 2 focusing on the smallest (25 percentile of area) triangles. In the ideal case these would all be one, hence the lower the mean the better the result.

9.3 Parameterisation

The functional grid can be influenced by a number of different parameters. The most influential of these are the size of a grid cell and the parameters of the smoothing operation, that is, the number of passes and the central weight of a cell.

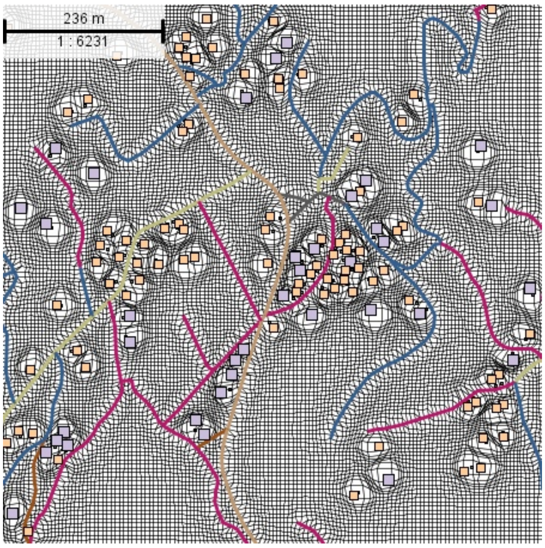
9.3.1 Cell Size

Figure 9.1 shows the effect of using a smaller sized grid unit on the map Example 2, together with the previously shown example from Table 9.2 for comparison. Since the technique was implemented using a process of subdivision of cells, the cells are one half of the size of those used before.

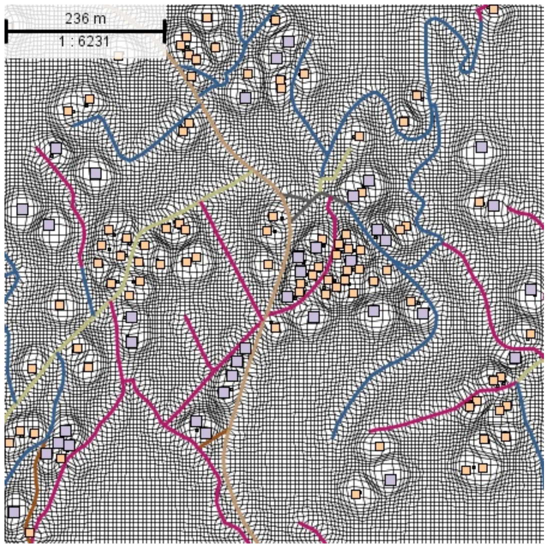
Figure 9.1 shows the transformations resulting from two different parameter settings. In both cases, the localised support of the transform is much clearer and better defined than for the grid with the larger cell size. One effect of the grid size is that the movements of points appear more controlled. For example in the dense area at the centre of the map symbols that hadn't been separated so well previously are now better positioned. Symbols that were previously moved too far previously are also now better spaced. The reason for that is that points more frequently occupy a single cell and so the displacement is able to operate in a more consistent way. When many points are contained in a cell there is an element of luck due to where they were placed that helps determine the quality of the result. In addition because the bilinear transform that is used to perform the projection of points within a cell is now working over a smaller area the amount of error that can be introduced by it is much reduced.

One disadvantage is that even with quite strong smoothing the distance that the energy is dispersed over the grid is very tight, as evidenced by the strong definition in the grid. This restricts the amount the points are separated by and so it is often still insufficient. Related to this is that individual clusters of points, i.e. where the magnification is uniform, are much smaller resulting in a surface that looks quite bumpy. This can cause problems for managing spatial relationships because the regions between clusters tend to absorb most of the energy, i.e the cells get smaller, which causes the relationships between cluster to be distorted. If this clusters are too smaller, in comparison to how they are visually recognised, this effect means that the appearance of spatial relationships will be lost.

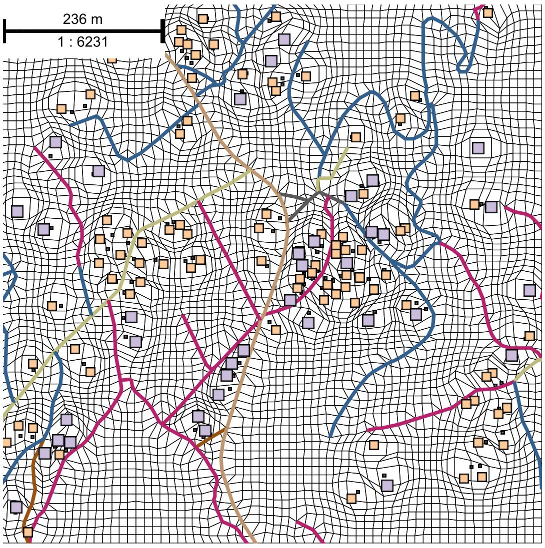
The number of passes of the smoothing operator can be increased to disperse the energy over a wider area, though as can be seen for the different values used, whilst the number of cells being magnified around a particular point has increased, the distance over which the energy is dispersed in absolute terms is fairly similar. This is because the distortion of the cells that have not been magnified, beyond the need to maintain their initial unit area, is mainly being governed by the conformal (MIPS) component of the energy. Since such cells now cover a much wider area this component of the energy is having a much stronger effect and limiting the amount of overall dispersion. Of course, ultimately the fixed map boundary itself will also



(a) Functional Grid: Wt 10, It 2



(b) Functional Grid: Wt 10, It 5



(c) Functional Grid: Regular size

Figure 9.1: The effect of different smoothing parameters on the functional transformation when using a fine grid (3.5 pixels^2 per cell). The grid used previously in Table 9.2 is also shown for comparison (c).

have a critical effect in this regard.

9.3.2 Smoothing Parameters

The effect of the smoothing parameter is considered only using the edge length and angular measures derived for the triangulation. Map example 2 is used in all the experiments.

Figures 9.3 and 9.2 illustrate the effects of varying the two smoothing parameters on the amount of conflicts, for the smaller symbol size and the finer grid (3.5 pixels^2 per cell).

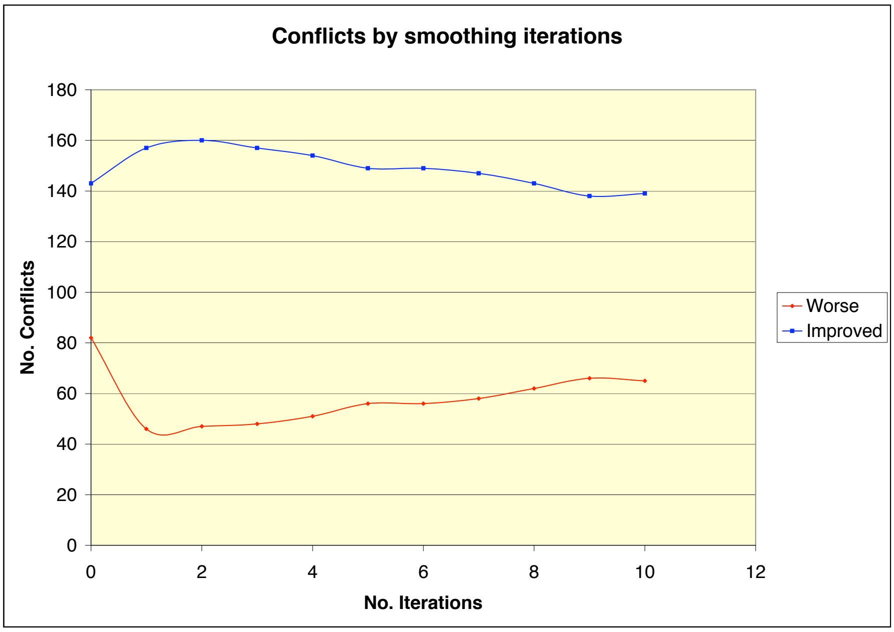


Figure 9.2: The effect of varying the number of iterations of the smoothing operation on the number of conflicts improved or worsened. A weight of 10 is applied for the smoothing operation, regular sized symbols and the grid with a smaller cell size (3.5 pixels^2) are used on map Example 2.

Probably the biggest difference in the quality of the result is between no smoothing and some. Whilst, too many passes of the operator reduces the number of improved conflicts to fewer than without the operator. The number of cases worsened is still much less. The weighting has a less significant effect than the number of iterations. Since it is using a fixed number of iterations at the point were these are best, i.e. two, this implies that an using the optimal number of iterations of the smoothing is an important factor than parameterising the weight, which is more a fine tuning.

The weighting is fairly level over its range, though there is a slight peak at around ten. Intuitively the peak probably has some significant. Low weights will result in a

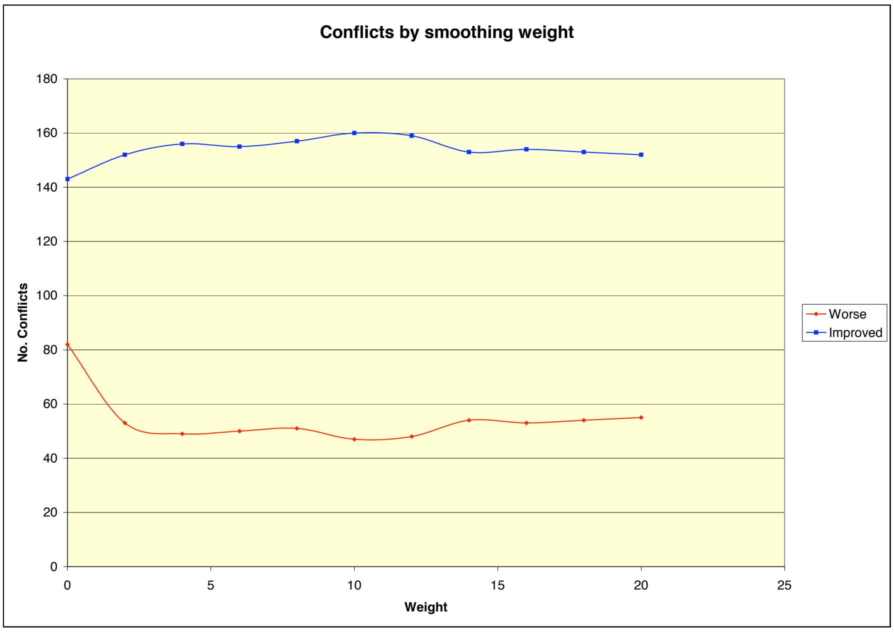


Figure 9.3: The effect of varying the weighting parameter on the numbers of conflicts improved or worsened. Here the regular symbol size is used with a fine grid size (3.5 pixels^2 per cell) on map Example 2. 2 iterations of the smoothing operation are applied.

more even distribution of the energy but because of this in any particular cell it will be reduced, meaning that the amount of displacement possible will be less. For high values the distribution will be small meaning that more space will be lost between clusters of points which would reduce the effectiveness of displacement, particularly where the density of points is high or the available space is limited.

Figures 9.5 and 9.4 show the effect of the smoothing parameters on the mean of the MIPS energy of a triangulation. Because the mean is being employed there is a much greater susceptibility to outliers making the trends less consistent, as preservation of spatial relationships is best when the mean is lowest. Two means are shown, one based on all the triangles related to points-of-interest and the other related to the smallest 25%.

As for the conflicts, the number of iterations has a more pronounced effect than the weight setting, especially for the smallest 25%. This again suggests that there is an optimal number of passes of between two and five times and after that the quality is not improved. The effect of the weight is much smaller, with a suggestion that lower weights result in better quality. This is to be expected since the lower values result in a more uniform spread of the energy due to greater contributing of magnification values amongst the cells.

Figures 9.7 and 9.6 use the bigger sized symbols and the coarser grid, the range of weights tested is also greater.

The effects of the parameters are more pronounced than in the previous examples.

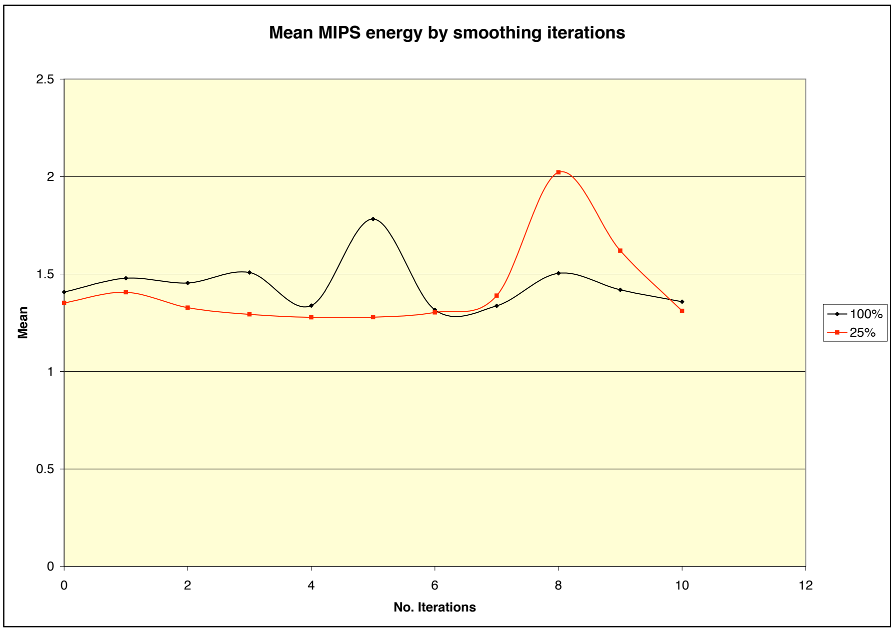


Figure 9.4: The effect of varying the number of iterations of the smoothing operation on the mean MIPS energy for map Example 2. A weight of 10 is applied for the smoothing operation, regular sized symbols and the grid with a smaller cell size (3.5 pixels^2) are used.

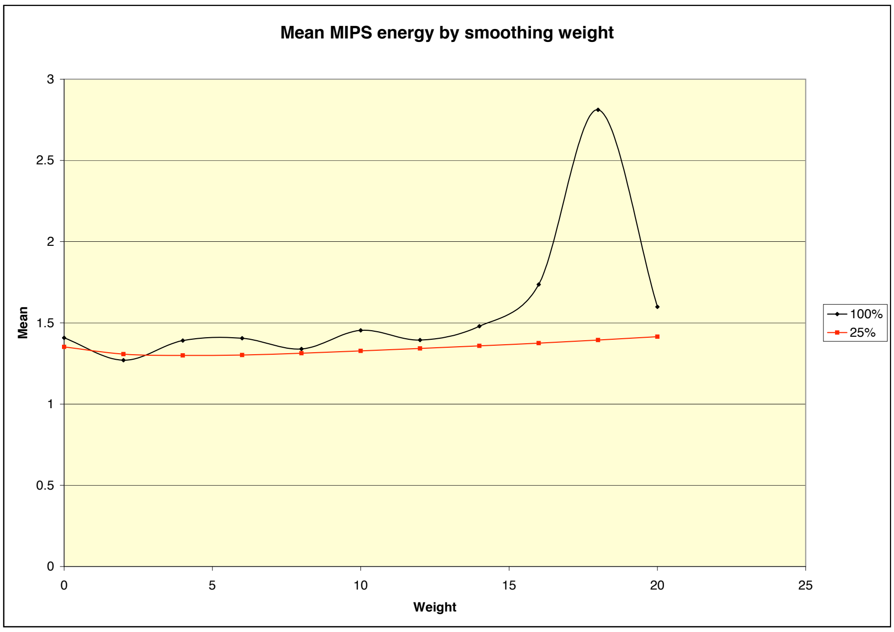


Figure 9.5: The effect of varying the weighting parameter on the mean of the MIPS energy for map Example 2. Here the regular symbol size is used with a fine grid size (3.5 pixels^2 per cell). 2 iterations of the smoothing operation are applied.

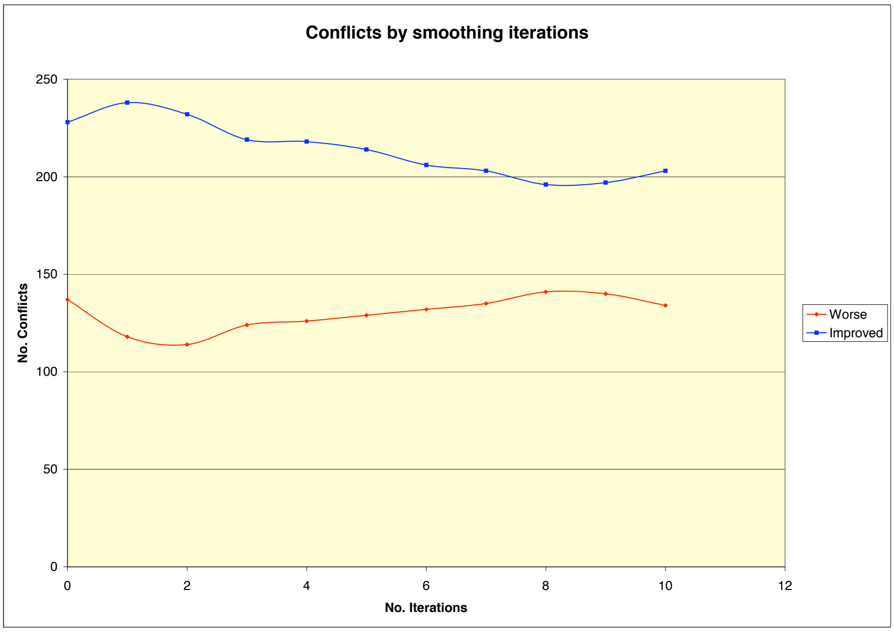


Figure 9.6: The effect of varying the number of iterations of the smoothing operation on the number of conflicts improved or worsened. A weight of 10 is applied for the smoothing operation, enlarged sized symbols and the grid with a regular cell size (7 pixels^2 per cell) are used on map Example 2.

Figure 9.7: The effect of varying the weighting parameter on the numbers of conflicts improved or worsened. Here the enlarged symbol size is used with a regular grid size (7 pixels^2 per cell) on map Example 2. 2 iterations of the smoothing operation are applied.

This is because the magnification values are much larger, and hence there is more energy to be distributed. Since the cell size is also larger the smoothing will also distribute these values over a wider area. Over a large part of the range for the parameters values, the result is actually worse than if no smoothing were applied. This is not entirely surprising, since when no smoothing is applied there is still a degree of uniformity in the resultant distributions of areas due to the conformal energy acting to preserve the overall shapes of cells independently of their areas and hence a cell is induced to grow (to achieve the same shape) if its neighbours grow. A peak can be seen for low numbers of iterations (one to two), after which the quality drops. For the weights there is a general trend towards improvement over the entire range. The implication here is that number of iterations being used, two, causes too much dispersion and hence the increased weight works against this trying to keep the dispersion small.

Figures 9.8 and 9.9 show a graphs of the mean MIPS energy as a function of the smoothing parameters for the larger sized symbology. The number of iterations

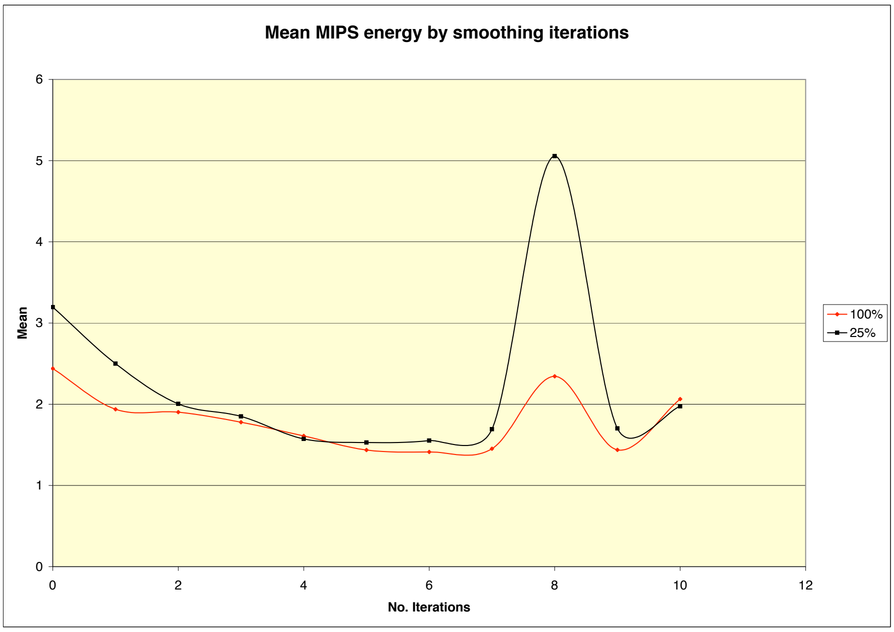


Figure 9.8: The effect of varying the number of iterations of the smoothing operation on the mean MIPS energy for map Example 2. A weight of 10 is applied for the smoothing operation, enlarged symbols and the regular sized grid (7 pixels^2 per cell) are used.

improved the solution initially but this effect levels out afterwards. The implication is that as the dispersion of the energy becomes more and more uniform there is less space for the distortion to take place in and so overall the transformation is fairly weak.

For the weights, the general tendency is that the increasing value reduces the quality of the solution following an initial improvement. In part it should be expected that the preservation of spatial relationships will be reduced as features become moved apart, since there must be to some degree a trade-off between these two factors. This is reflected in comparing the trend shown by the conflicts in Figure 9.7 where the increased weight is improving the separation.

There is also a peak at around fourteen. This can't be put down to purely the poor sensitivity of the mean to outliers because the values either side are also relatively high. Consulting the results for these values indicates that this peak occurs because a group of points are not being moved away from a road. This happens because the smoothing operation is not constrained by the road, allowing the magnification values to 'leak' over it. Hence the transformation in that cell is able to propagated to the other side of the road. Before the peak the distribution is spread out enough that there is not real gradient in the magnification values on other side of the road. After the peak, the distribution of magnification values is sufficiently compact that there is a region of low magnification just behind the group and away from the road which can be take up the deformation instead. These are two problems with the present implementation. The transformation should be limited better where a road crosses a cell diagonally and the smoothing operator should be bound to the road network.

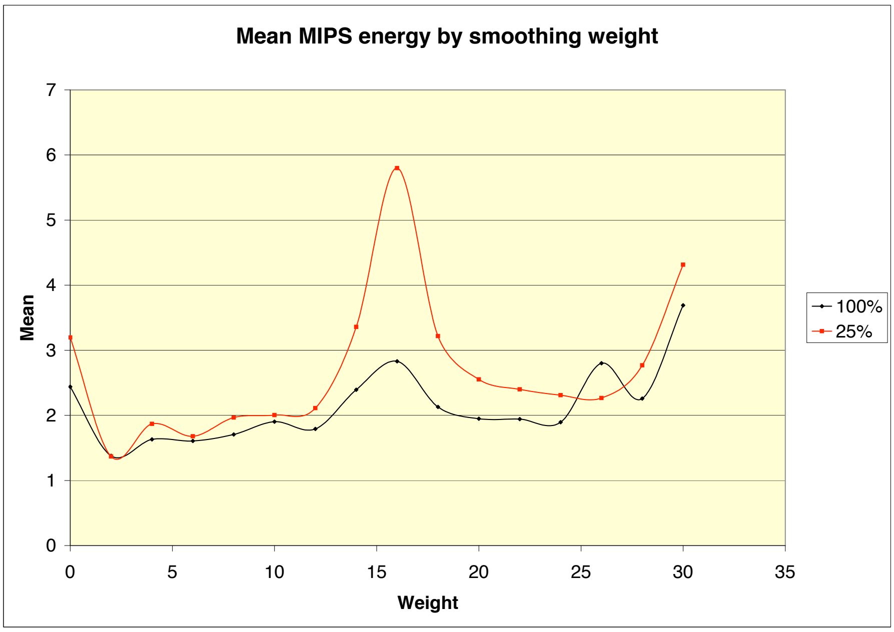


Figure 9.9: The effect of varying the weighting parameter on the mean of the MIPS energy for map Example 2. Here the enlarged symbol size is used with a regular grid size (7 pixels^2 per cell). 2 iterations of the smoothing operation are applied.

9.4 Running Times and Convergence

Performance was evaluated on desktop PC with an 2.13GHz processor running a Java 1.4 virtual machine. All methods were implemented as extensions to the Deegree Web Map Server, details can be found in (Edwardes et al., 2003a).

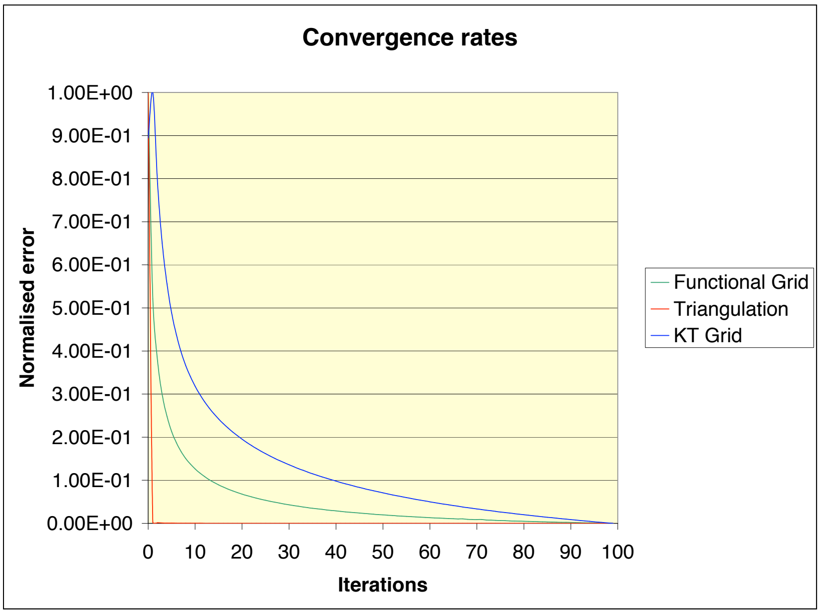
Figure 9.10 shows the convergence rates of the three approaches on linear and log scales. The error values have been normalised over their ranges so as to lie between values of one and zero.

The time taken for each method to converge to an adequate solution was 151 seconds for the functional grid over 50 iterations, 12 seconds for the triangulation over 50 iterations, and 2 seconds for the KT-grid over 164 iterations (based on convergence of the root mean squared error).

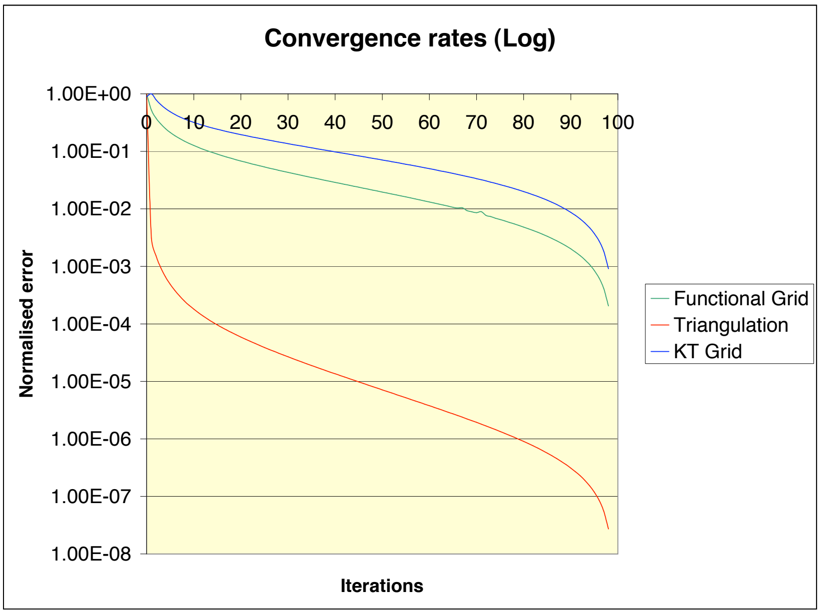
A number of interesting observations can be made about these results. The convergence of the triangulation is extremely rapid, with most of the solution being obtained in the first few iterations. There are two main reasons for this. Firstly, a 1-ring of triangles usually covers a larger area than the equivalent region for the grid cells (the convex hull of the four neighbours of a node). This means that in a single iteration a point in the triangulation can be moved closer to its final minimum than for the grids. For the grid nodes the relaxation is more gradual as the transformation diffuses over the space and hence the convergence is slower. Secondly, the constraints on the triangulation are relaxed after each iteration which will necessarily cause the method to converge more quickly. However, the suggestion here and from the results of the qualitative analysis is that this constraint relaxation probably goes too far, at least in terms of the preserving spatial relationships.

The rate the functional grid converges at is more rapid than for the KT-grid. This is probably because the functional grid is able to place nodes more optimally at any particular iteration. Because the KT-grid limits the amount of displacement of the nodes neighbouring a point so as to be equal in each direction the solution will to some extent be under-relaxed and thus converge more slowly.

The relatively slow rate of convergence of the KT-grid is offset by the time taken to compute a solution which is far quicker than for any of the other solutions. The functional grid fares the worst in terms of the overall time taken, well outside the time that is acceptable for online application. The main cost is from minimising the functional, rather than other operations such as the feature alignment or the smoothing. However, the implementation was not made taking performance much into account, and since the rate of convergence of the functional grid is good it is conceivable that code optimisation of the functional minimisation would lead to far more acceptable performance. The choice of 50 iterations may also be too conservative with good results still being achieved with far fewer. The performance time for the triangulation was acceptable. The main issue here is that the triangulation will be more susceptible to greater running times as the volume of data increases, since it produces more triangles and thus requires more time both to compute the transformation and to generate the initial triangulation. The performance of the



(a) Convergence (linear scale)



(b) Convergence (log scale)

Figure 9.10: Convergence rates of the three methods plotted on linear and log scales over 100 iterations. The amount of error at each iteration has been normalised over the range of values for the purposes of comparison.

functional grid on the other hand is primarily dependent on the number of grid cells, so increasing the volume of information will have less impact.

9.5 Discussion

In Section 8.1.3, four needs for a dynamic view were presented. Here each of these is reviewed in turn with respect to the results.

9.5.1 Referential Integrity

The first need was that, "The relationship between the user's absolute position and the features of interest should be maintained. That is, it must be possible to project the user's position in such a way that their spatial relationships to the information being presented is faithful to how they will experience that information in the real world.". Essentially, this consideration deals with the requirement that the view should operate in an independent and dynamic way and be able to communicate spatial information faithfully as the user's locational context changes.

For the two grid based approaches this consideration is relatively straight forward to ensure, so long as the shape of the quadrilateral cells is convex. Constraints are implemented to ensure cells are well shaped but where they become strongly compressed this could theoretically cause problems. For the KT-grid the user's position can be indexed within the grid by simply looking up the cell that contains it and then re-projecting the point within this cell to the final quadrilateral using a forward bilinear transform (as described in Equation 8.3). The functional grid is similar, except because the cells have been aligned to the features at the start a supplementary index is used to identify the initial quad. The index was illustrated in Figure 8.17.

The bilinear projection is also slightly more complicated since the initial shape of a cell may not be a square. To perform the projection the point must first be projected from an arbitrary quadrilateral to the unit square, which uses a inverse bilinear transform, and then from the unit square to the new quadrilateral, using a forward transform again. The inverse bilinear transformation involves finding, and selecting amongst, the roots of a quadratic equation which is solvable but more complex and can introduce more error than the forward transformation.

A system for projecting an arbitrary point using the triangulation was not explicitly developed here. However, it can be assumed that this would not be so simple to perform. A more substantial spatial indexing system, for example similar to the binary-space partitioning tree previously described in Figure 8.16, would be necessary to identify the triangle containing the position, as well as a method to perform the projection based on a pair of triangles, for example using barycentric coordinates.

9.5.2 Topological Relationships

The second need was that, "The configurations of the most important static geographic features (e.g. roads, paths and rivers), and relationships of the dynamic data with these should be preserved. More generally, the topological and spatial relationships between the main structural features of the map, for example containment within cycles of a road network and adjacency with rivers, and the foreground data should be preserved. For instance, a foreground feature should always remain on the same side of a structural, background, element.".

This then really considers the issue of preserving topology between the different types of data. The KT-grid had the most problems to meet this goal. The method for managing topology was to assume that as long as the network features contributed to the magnification the foreground features should not cross them, since they would be pushed away. This method works to some extent if the network of linear features is dense and fairly uniformly distributed but in other cases performs badly. It may be possible to define a stronger constraint that fixes the cells surrounding a line but to be effective a grid with a very fine mesh size would be required.

The two methods based on a functional had explicit methods to control topology by aligning data structures with the features and then pinning the data structures at those points. This method worked well, though there is room for some improvements to the implementation. For the functional grid the main problem that can occur is that illustrated in Table 9.11, where a sharp partition can pin most or all the degrees of freedom available to define the transformation, i.e. the quadrilateral is unable to change shape. This means the position of the feature becomes trapped. One method to overcome this problem would be to allow nodes that are pinned to the edge of a linear feature to move along the edges of these. Hence, the topology would be maintained but the greater amount of freedom would be afforded to the transformation of a quad.

9.5.3 Spatial Relationships

The third condition was stated that, "The spatial relationships amongst the dynamic features (i.e. spatial patterns amongst points of interest) should be conserved.". In the main, each method was able to achieve this goal without very significant differences in the overall distributions of points produced, for example see Tables 9.21 and 9.34.

For the grid based methods a strong influence was the size of the support, the area over which the magnification was propagated. In particular, this affected how points ended up being grouped together with a fairly uniform magnification being applied across such clusters. For the KT-grid, the support was much wider than for the functional grid. Often this was an advantage, but at other times it could cause the magnification of a group of points to affect too many other points over a large distance. The functional grid had a much smaller support largely due to the condition of conformality on unmagnified cells acting to constrain how far the magnification could be spread.

A smoothing operation based on spatial averaging was applied to attempt to control this better. Particularly for the larger sized symbols this had a positive effect on spatial relationships, as shown by the Figures 9.9 and 9.8. However, as can be seen by the figures of the fine grids in Figure 9.1, the absolute distance over which the magnification is propagated can remain similar for quite different parameterisations. This is not such a bad thing, in general a more local support is desirable since it provides more control. This was evidenced by the better results of the functional grid overall in terms of how it compromised between spatial relationships and amount of separation. The main problem is that clusters of points that are more widely distributed can end up getting distorted as the transformation over exploits the regions of lower magnification between the points, i.e. within the cluster rather than around the outside.

The support is largely a function of the cell size, this can make parameterisation amongst the three variables (cell size, number of smoothing passes, and smoothing weight) quite complicated. Alternative methods to the smoothing are also possible that might yield better results. One technique used often in finite element methods is to define impulse points, here these would be the magnification at a point-of-interest, using Gaussians that distribute the (magnification) function over a region. This approach would require that the distribution of magnification for a point is then integrated over the cells where it falls, which is not simple. In addition a method to decide how to combine the contributions of separate magnifications that overlap a cell is also needed, for example by summation or by averaging.

The triangulation method tended to favour separating points over preserving spatial relationships. This was a consequence of relaxing the control over spatial relationships over subsequent iterations of the technique. In some cases the resultant effect was quite desirable, for example in Figures 9.29 and 9.30 whilst in others this was less so.

The main difficulty was to formulate the functional in the triangulation in an appropriate way. One problem, was to convert between displacement constraints that were defined according to the lengths of edges and an energy that was based on area. The method of weighting the components of the area calculation provided satisfactory results but was not ideal.

A further issue for the triangulation was how to deal with the propagation distance. This is problematic since, on the one hand, it essentially supposes that certain relationships can be ignored whilst, on the other, these must somehow be represented in the minimisation calculation. In the implemented method this was performed by setting the scaling of edges that were longer than the propagation distance to unity (see Equation 8.19) and then relax this value on subsequent iterations, unless the edge had shrunk too far. This method is not ideal, since it still does not describe adequately how the propagation should operate and as such can cause relationships to be considered in the minimisation that should not be because it will still attempt to ensure that the non-propagating edges maintain their same length.

Another problem with the propagation was that no attempt was made to formulate how the maintenance of angles should be propagated over a triangle, instead this constraint was relaxed over consecutive operations.

9.5.4 Separation

The last stated need was that, "The amount of overlap between dynamically generated symbols should be minimised, and thus interaction with the displayed data enabled." For the most part all the methods achieved this goal for both the regular and enlarged symbol sizes, at least in terms of separating symbols enough that they could be interacted with. Whilst new conflicts were often created as indicated in the tables of Sections 9.1.7 and 9.2.5, this was usually because the new positions found were a compromise overall, i.e. they created smaller new conflicts in exchange for reducing the original ones.

The two grid methods were similar, though the KT-grid usually generally displaced less than the functional method. To some extent this was because the functional method tended to over displace symbols rather than any particular failing on the part of the KT-grid. It would also indicate that the KT-grid could be better parameterised to induce more magnification.

The main problem for the KT-grid otherwise was the lack of a pinning constraint. This meant too often points would be displaced into or over the road network or the transformation would not be restricted adequately within a partition to find a suitable solution there. For both grids, if points fell within the same cell and were close together it was very difficult to achieve a satisfactory separation, see for example Table 9.6. This could be possibly improved by defining a higher order projection to the bilinear one that could take into account the initial distribution of points within a cell and distribute the area within the cell to better account for this.

It is not surprising that the triangulation performed best at separating points, and in particular points that were very close together, since it is structured to consider precisely these situations. The main issue was in its balancing between separating points and maintaining spatial relationships, where the method favoured the former more strongly.

9.5.5 Overall

Overall the functional grid probably attained the best results in terms of a compromise between separation and preservation of topological and spatial relations. The main problem is that as the running times show in Section 9.4, it is too slow in its current implementation for online deployment and too processor intensive to be used on a mobile device. That said, the method was not implemented with speed as a main consideration but was more concerned with achieving the best possible results from a portrayal point of view.

One way in which the technique can be optimised for mobile devices is by pre-computing and caching the feature aligned grid, this allows how foreground and background features are handled to be completely separated. However, the bottleneck was largely in minimising the functional during the computation of the the transformation rather than other operations such as smoothing or aligning the grid to the features.

There are various methods that could be used to improve this. One approach would be to implement a multi-grid that adapts its resolution across the map space according to the distribution of information. The main difficulty with this is how to deal with the computation of the transformation at the boundaries between cells of different sizes.

Another approach is to order the nodes in a priority queue and always solve the worst case (that with the longest partial derivative vector). This approach was tried during the implementation. The main problem encountered was that the search for a solution could get caught up trying to continually improve the placement for a small set of nodes. In spite of this a more effective method based on such a queue is conceivable.

A further possibility is to parallelise the functional. Since each 1-ring is considered independently these could be processed within their own execution threads quite easily. Of course, this would only really make sense in a server deployment rather than on a client device. An alternative approach which minimises similar properties to the functional has also been implemented to run as an interactive tool. It is described later in Section 9.6. This method might provide a more appropriate method for real-time interaction on a client device, but does not allow as much control.

The KT-grid had the advantage over the other techniques of speed. Though when tested on a client running the WebPark application it was still too slow and too resource intensive. Partly, this was because the processor was shared amongst several applications running on a Java virtual machine on the device. The implementation of this could be made faster by implementing it natively.

The main problem it suffered from was the lack of a strong constraint to maintain topological relationships with background features. The implementation assumed a starting state of a regular grid which meant that the feature alignment technique was not applicable. However, it is conceivable that a method to better control could be found.

The triangulation performed well particularly in terms of separating points and in times that were acceptable for online use for the examples used. However, it is unlikely that it would perform well within the computation constraints imposed by a client device. In addition, with greater densities of information the costs of both computing the triangulation and minimising the functional would likely become prohibitive.

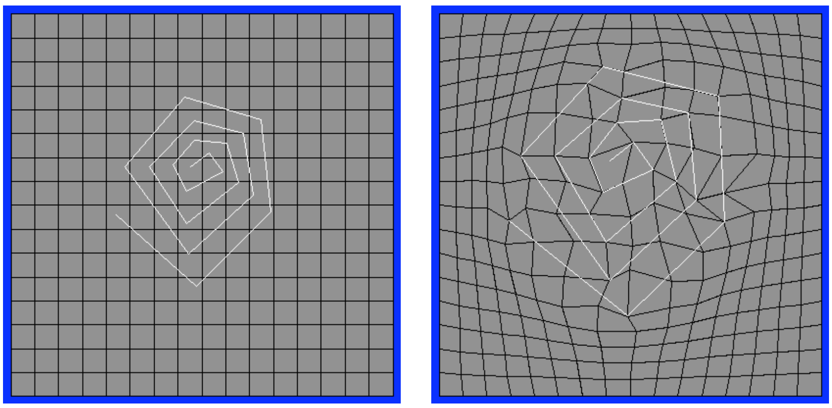
The main disadvantage is that it is difficult to separate the handling of foreground and background information. A mesh could be pre-defined based on linear background features and then this re-meshed to take into account the foreground data, but this option is far from ideal. In addition, projecting the user's location within the transformed data space is not as straight forward as it is for the grids.

9.6 Extensions of the Grid

There are two conceivable ways that a grid data structure could be extended. One is by allowing other feature types to be repositioned using it. The other is by improving the speed of its operation.

9.6.1 Re-organising Lines

The most obvious way to extend the capabilities of the grid approach is by allowing it to displace linear features. Figure 9.11 illustrates an experiment to allow this. Here the grid nodes are not locked to the feature and so the transformation is unconstrained. After the transformation the vertices of the line are then re-projected. Figure 9.11 shows there is some potential for performing the operation but simply



(a) Untransformed (b) Transformed

Figure 9.11: Experiments in displacing a line using the transformation. The nodes of the grid are not fixed and the vertices of the line are reprojected after the transformation is applied.

unpinning the nodes is not a enough. For example, at the bottom left of the feature in the figure, it can be seen that the underlying grid has moved quite far away from the line, which means that not only is the line not displaced far enough but the shared topology is also changed to a degree that is no longer acceptable.

9.6.2 Laplacian Smoothing

An alternative approach to minimising the properties that are considered by the functional is based on the observation that a functional that minimises the Dirichlet energy, described in Equation 8.11, will also satisfy the Laplace equations (Floater and Hormann, 2005). For a planar mapping with coordinate functions $x(u, v)$ and $y(u, v)$, these can be written:

$$\frac{\partial^2 x}{\partial u^2} + \frac{\partial^2 x}{\partial v^2} = 0 = \frac{\partial^2 y}{\partial u^2} + \frac{\partial^2 y}{\partial v^2} \tag{9.1}$$

Transformations that meet these criteria are called harmonic functions. Whilst a conformal transformation is harmonic, harmonic functions are not generally conformal. However, they will bring the solution close and they are fast to approximate.

In finite difference analysis approximate solutions to the Laplace equations are obtained by requiring that the position of a mesh point is equal to the average of its neighbouring points (Tobler, 1994). In the computer graphics literature the technique is used to smooth the representation of a surface, this is generally called Laplacian smoothing (Field, 1988). This principal is employed here to experiment with a transformation that can be computed fast enough to allow interactive manipulation of the feature aligned grid. For example by adding points and having the grid react in response immediately.

The method works by computing the position of a node from the weighted average of its neighbours. The weights are used to add information about the symbolisation. The positions are computed using a primal-dual scheme (Taubin, 2002). This uses a primal network of grid nodes, as well as a dual network computed from the centroids of the cells. The positions of the centroids are used to compute the positions of the grid nodes and likewise the positions of the grid nodes are used to compute the positions of the centroids. Figure 9.12 illustrates the two types of grid.

When foreground features are added to a cell the magnification due to their symbology is accumulated as a weight on the cell centroid (dual node). In its current state weights for multiple points in a cell are simply added together and then smoothed using spatial averaging in a similar way to that described in Section 8.2.8. The main differences in the smoothing is that in the current implementation contributions between cells are not weighted by the shared edge length, a nine cell kernel is used instead of a five one, and only one iteration is performed. The smoothing adds little cost in computation since only the cells directly influenced by the smoothing kernel need to be considered instead of the entire grid.

The transformation is performed by iterating over the grid, first positioning the nodes of the primal grid according to the weighted nodes (centroids) of the dual grid and then positioning the nodes of the dual grid according to the positions of the nodes of the primal grid. The equation for determining the position of a dual node (the centroid) is given:

$$D_{i,j} = \frac{1}{4}(P_{i,j} + P_{i+1,j} + P_{i+1,j+1} + P_{i,j+1}) \tag{9.2}$$

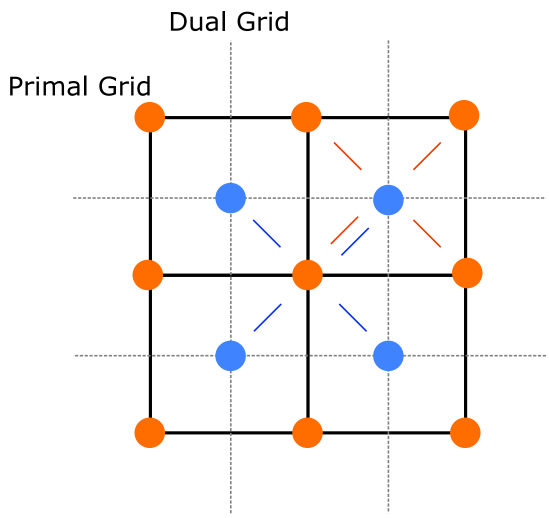


Figure 9.12: The primal and dual grids. The primal grid is shown in bold with the nodes of the grid shown in red. The dual grid is shown dashed with the nodes in blue. The dual nodes that contribute to the position of the central primal node are shown with lines linking the nodes. The same is shown for the primal nodes that contribute to the position of the dual node in the top right corner.

where $D_{i,j}$ is the (i, j)th node of the dual grid and $P_{i,j}$ is the (i, j)th node of the primal grid. The x and y coordinates of the node are computed separately. Hence, the x coordinate of the dual node is given simply by the average of the x coordinates of its primal neighbours, and respectively for the y coordinate. For the primal node the equation is:

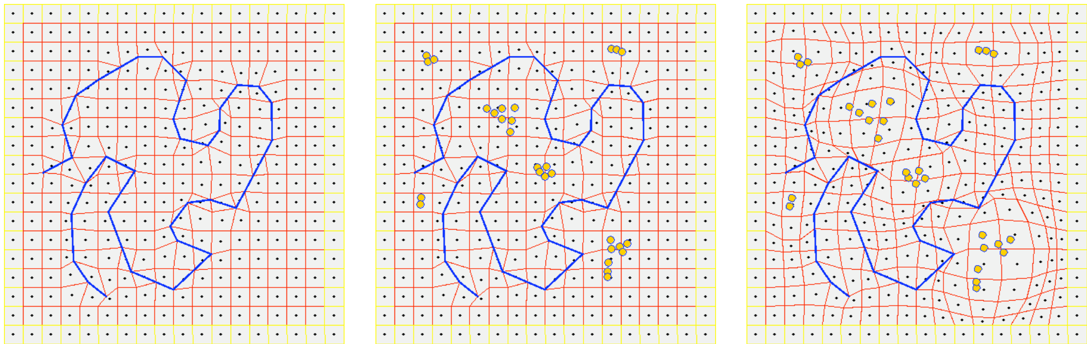
$$P_{i,j} = W_{i-1,j-1}D_{i-1,j-1} + W_{i,j-1}D_{i,j-1} + W_{i,j}D_{i,j} + W_{i-1,j}D_{i-1,j} \tag{9.3}$$

Here, $W_{i,j}$ are the centroid weights computed from the points-of-interest. The weight is actually the inverse of the value stored (normalised over the sum of the weights), since the lower the weight the smaller will be the contribution of the dual node to the position of the primal one and so the further the primal node will end up from it. Thus, the weights can be thought of repelling or attracting the primal node.

One advantage of the approach is that because the position of a node is based on the (weighted) average of the centroids, the node's final position must always be within the convex hull formed by them and hence the grid cells will always remain convex obviating the need for additional routines to check for this. Boundary conditions are implemented by adding a boundary one cell wide to the grid. The positions of nodes of these cells remain fixed but they contribute to the calculation of the cells inside the grid.

Figure 9.13 illustrates the approach in use for a small set of example data.

In the implementation the state shown in the middle graphic of Figure 9.13 is never actually seen. When a point is added the transformation of the grid is immediately updated.



(a) Grid aligned with features (b) Set of points (c) Points transformed

Figure 9.13: Re-organisation of points of interest using Laplacian smoothing. The primal grid is shown with red cells and their the boundary cells, used to enforce the boundary conditions, shown in yellow. The small black points indicate the nodes of the dual grid (i.e the centroids). The grid has been initially fitted to a single feature line shown in blue. Foreground points are shown in orange.

The results are remarkably similar to those of the functional grid, but over barely perceptible computation times. The main problem is that the operation is much less controllable. Relating weights to areas that cells should reach is not straight forward, parameterisation here has been based on trial and error.

Chapter 10

Discussion

10.1 Methods for Analysis and Design

In Section 1.3 the questions directing this work were laid out. In this Chapter these questions will be re-visited and discussed in light of the concepts and algorithms developed and the experiments performed.

The first research question was examined in Chapters 2 and 4. It concerned the identification and use of different geographical perspectives in the development of location based services. It was stated:

- "What are the essential characteristics of Space, Place and Region that should be employed in the analysis and design of location based services?"
  - "How can these be effectively identified in an analysis process?"
  - "How can they inform the different elements of LBS design?"

Mobile Geographies

Chapter 2 examined how the concepts of Space, Place and Region, which underlie much of geographical theory, might be relevant to the development of 'Mobile Geographies' (Livingstone, 2003). The motivation for exploring this question was that the special characteristics of location based services, as service based and ego-centric technologies, mean their design needs to move away from the static, universal viewpoints inherent in more conventional methods for presenting geographic information.

Perhaps the most important point identified here was that these three concepts do not represent different types of abstractions of geographic phenomena that can be easily modelled and represented. Rather, they constitute different perspectives that people use to structure and encode their knowledge and experiences of the world. Whilst each to some extent can be represented by another, doing so results in inconsistencies due to what is termed by Curry (2002) *discursive displacement*. Many of the problems encountered in designing location based services are accountable to discursive displacement. For example, the vagueness of boundaries in the spatial instantiation of regions and the ambiguity of location that can be described simultaneously in many different senses (e.g. 'Here') (Schlieder et al., 2001; Tversky, 2002).

Creating Places

At different times in the design of an LBS particular perspectives will tend to dominate, though when using an LBS all might be simultaneously relevant. Place was suggested to be inherent in the direct, first-person encounter of the world and in how people see the environment as affording different opportunities to engage in particular activities.

Place is probably the most important perspective in LBS because it relates to an ego-centric point of view and unites various considerations such as activity and location as a setting for these. However, it is very difficult, if not impossible, to capture the full range of facets of Place within a service since these largely emerge through people's subjective perceptions and experiences. Instead, LBS need to present spaces in such a way that users can *create places* themselves through their interactions with the environment. This is both by contextualising information to support the user in exploring their surroundings, for example by enhancing the meaning of locations through information about things that occur or have happened there, and by presenting the physical characteristics of a setting in ways that allow the users to better orientate themselves within the information presentation. For example, by representing geographic information through narrative based models (e.g. route guides) or photo-realistic virtual environments. How these aspects were considered in this work is discussed later in Section 10.2.

Modelling Regions

Regions were found to dominate the way in which geography is cognitively organised by systems for categorisation. In some senses regions were difficult to distinguish from places. This is particularly the case when places are considered as something with a *de facto* identity (e.g. with a place name).

Places so defined can be considered as sub-classes of the concept of region (Agarwal, 2004) since they share many of the same characteristics (e.g. ontological and qualitative definition) and inherit many of the same problems for representation within an LBS. Again, this can be seen as a result of discursive displacement where communal perceptions of the qualities of a place have become categorised within an objective identifiable entity.

Regions offer the potential to allow LBS to categorise information geographically and so redefine location as a spatio-semantic index. Two issues arise out of this. The first is that regions are not inherently spatial entities, they are instances of qualitatively defined categories, but their use in LBS necessitates their quantification. This means they will usually have vague and uncertain boundaries. The method of *satisficing* suggested by Hill (2000) for organising gazetteers and geo-ontologies

(Jones et al., 2001) was found pertinent to addressing this problem. The second issue is how to select the semantics of regions such that they are defined in relation to the information that they are used to organise. This issue is discussed further in relation to 'Geo-enabling' in Section 10.2.

Spatial Representations

Space was highlighted as a perspective that needs to be treated with some caution in LBS. On the one hand, it is essential to encode and manage much of the data that is employed by an LBS. One of the main issues highlighted in relation to this was the problem of reusing geo-spatial data that have been captured for other requirements than the service. This often resulted in ontological, spatial and temporal *mismatches* between the different purposes (Dias et al., 2004b). On the other hand, the space perspective was found problematic because it is *sticky*, in the sense that it can introduce a particular view point on how information should also be presented when this may not be fundamentally appropriate.

Visually, the spatial view point is most useful for presenting relatively static, descriptive information about geographic patterns and distributions that are largely independent of the particular situation of the user. At other times its role is more in the background, underpinning the alternative perspectives rather than subsuming them.

One example of problems that can occur when the spatial perspective is overemphasised was in the definition of location as a "spatial scope". This recasts and limits the regional and place-based perspectives within a geometric substitute.

Another instance is in cartographic presentation where conventionally the focus of abstraction is on how geographic phenomena and the spatial relationships amongst them are represented. Whilst this form of abstraction is often relevant in LBS maps, the difference is that the focus for abstraction is not on the description of phenomena independent of the observer but rather the role that geographic phenomena play in structuring the setting for activities.

In spite of the problems of the spatial approach it was acknowledged that spatial representations and map-based services can offer much to LBS. Here, the map was employed as one visual component within a broader system for geographical presentation. From this standpoint the main issues identified were in how the map could be adapted dynamically to support the particular perspectives and contexts of the user.

Inductive Analysis of User Needs

Inductive approaches to analysing user needs were proposed in Chapter 4. These attempted to generate models of use and interaction grounded in observation as opposed to interpreting data based on predefined theory or cognitive constructs. The methodology employed drew on content analysis and grounded theory to analyse questions that visitors to the Swiss National Park had put to park guides.

The method described cannot be viewed as purely inductive since some theory and a limited set of predefined constructs (e.g. space, place, region and, object, subject, and action) were used to support the analysis and interpretation of the dataset. The analysis was also complemented by more ethnographic approaches, such as thinking aloud and participant observation, that were undertaken by other members of the WebPark consortium (Krug et al., 2003; Abderhalden and Krug, 2003).

Scoping Actions

To consider how places are created by activity the analysis looked at the ways in which actions were described. It was found that visitors tended to think of actions as either relating to themselves or to the features (e.g. wildlife) of interest.

For the former type, actions were often perceptual, for example seeing and hearing, or based on active exploration, such as finding and passing. These emphasised how the creation of places needs to be supported in ways that are unrestricted and spontaneous in response to the visitors' immediate and perceptual experiences of the world. Actions of the latter type related to a wide variety of relationships both amongst species, e.g. predation, between species and their environment, e.g. where they live, and related to the their life-cycles, e.g. breeding and blossoming. These types of action emphasised how places are created by adding meaning through a deeper knowledge of wildlife.

The analysis was developed into a model of action categories that the service should allow the visitor to perform:

- inform
- verify
- identify
- occur
- locate
- observe
- situate

These were compared to the actions that Reichenbacher (2004) describes for LBS and found to be reasonably similar, allowing systems of actions to be chained together in a same manner as he describes.

Semantic Granularity

The analysis also looked at how entities (e.g. subjects, objects, and locations) are described and related to actions, and the granularity of semantics employed for this. It was found that the level of granularity was often related to the type of action being performed by asking the question. For example, broader classes of entities and indexical pronouns were used in trying to identify species whereas more refined semantics were used to verify the identity or seek more detailed information. There was also some evidence that visitors used categorisation based on the types of *basic levels* suggested by Rosch (1978), though these would often be at more refined semantic levels than would usually be expected (e.g. Red Deer and Ibex instead of Deer or Ungulates). It was suggested here that these categories indicated certain species were seen as more prototypical of the animals living in the park.

Identifying Locations

The semantics used to describe locations provided insights into how visitors differentiated space as places and regions. Perhaps the most important observation was simply the variety of ways in which location is expressed in protected areas. In other situations these might be more limited, for example to named places and cardinal directions projected from these.

Two main categories of location were identified, direct and indirect places. Direct places related to where the visitor was or would be in the future. In this category the term 'Here' was most often used to denote the immediate surroundings. 'Here' is a highly ambiguous description of location, however its use echoes the act of creating a place by suggesting that the visitor finds something particular about their current situation which warrants further enquiry. The notion of 'Here' is largely embodied in LBS by scoping information to the user's position. Other descriptions of direct places would join indexical pronouns indicating the location with semantics to describe it, e.g. 'this meadow'. This implied a use of regions to categorise the place being experienced or at least to better delimit the extent of the surroundings meant.

Indirect places also usually indicated a region perspective. These used names or characteristics to describe places that were relevant but remote from the visitor. Often the semantics used were close to aspects of the wildlife they were being used to locate, for example as sites with affordances such as breeding and nesting. This was taken to suggest that in modelling locations as regions the qualities that define them should share some of the semantics of the features they will be used to index. A more spatial perspective was also inherent in some of the terms used. This was most evident for locations that described kinds of topographic entity, such as forests.

Canonical Questions

The ways in which questions were structured provided an insight into how information could be tied to the identified actions and locations and hence how interfaces might be designed to support visitors' activities. A set of five canonical questions were identified:

- What x is this?
- Is this an x?
- What x can be found at y?
- Are there x in y?
- Where can x be found?

Based on these a conceptual model was formulated that proposed a set of conceptual information domains:

- Descriptions
- Kinds
- Percepts
- Locations

These were linked together by the aforementioned actions to answer the questions, see Figures 4.2 and 4.3. At different points the links within this model embodied different types of geographical perspective. For example, place was implicit in relating locations to perceptual experiences by the action of observe, regions supported how locations were related to kinds through the action of occur, and space allowed different kinds to be located.

Limitations of Analysis Method

One problem of the methodology is that it relied too strongly on the visitors to express their desires for information in the absence of a sense of what could be available through an LBS. Often seeing how an application could look will stimulate a potential user's imagination, producing questions that they might not have been asked and so which can end up being overlooked when the analysis is translated into design. An example might be a simple question such as "What kinds of things can I find around me right now?".

To overcome such issues prototypes were shown at different stages throughout the project. A problem though is that prototypes will often not handle well. This can mean that questions become centred on the technical limitations of the prototype and over-shadow the ability to gain deeper understanding of the success of the design.

Another issue with the approach is that it was not easy to interpret exactly what the visitor was thinking when asking a question, since they may only be revealing a small part of their process of thought. This is symptomatic of a more general problem of using questions taken out of the context in which they were asked. This was particularly evident in the use of 'Here' to describe locations.

Ethnographic methods, such as videoing participant observation, can help to throw more light on the context of a question was asked in. Such techniques were employed at other stages of the process of identifying user needs but these could not be related to the database of questions employed here.

A final issue with using questions is that they are spoken and so already represent a particular way to describe the world. Perspectives such as space and place are particularly difficult to ascertain in this way because they are not easily formulated in natural language. Again, this issue can only be dealt with by employing multiple methods of analysis.

Testing the Model

The model developed from the analysis was used to design the architecture and flow of interaction presented in Chapters 5 and 7. Final testing of the WebPark platform was conducted in the summer of 2004 with 87 people completing a questionnaire about the service (Krug and Abderhalden, 2005). Of the questions asked during testing only a few were directly relevant to the species service, since the aim was more to evaluate the system in its entirety. Figure 10.1 describes the results that visitors felt about the overall ease of use of this service.

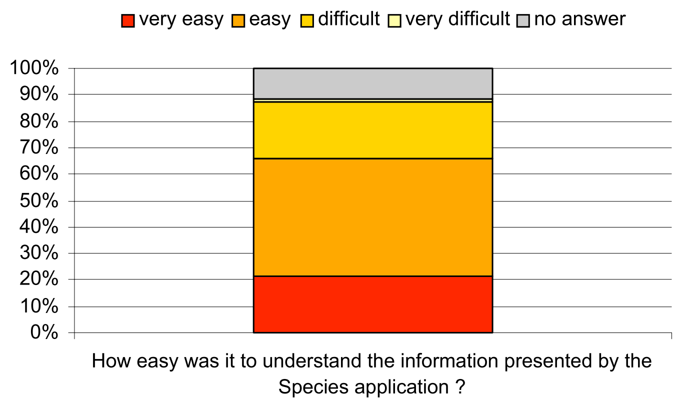


Figure 10.1: Results of user testing on comprehension of species search information. Figure reproduced from Krug and Abderhalden (2005).

The results are good, with the majority of respondents finding the presentation of the service easy or very easy to understand. This suggested that the approach to analysis had been relatively successful in translating how people think about wildlife and location into the design of the service.

10.2 Data Modelling

One of the main problems highlighted by the previous sections was that the perspectives of region and place are very difficult to realise since they are not inherently representational. Instead, they are developed through how information is managed and presented in a holistic and integrated manner. The question that is considered here is how this can be achieved practically by linking the different conceptual domains and actions with data modelling processes. This involved considering a multitude of heterogeneous data sources and how these could be transformed and linked together. The research question and sub-questions were stated as:

- "To what extent can the spatial modelling of information and location be influenced by the perspectives of space, place and region?"
  - "What qualities can be used to represent locations and how should these relate to the information they need to index?"
  - "How can users be supported in creating places through their activities?"
  - "How important are spatial representations of information, such as distributions, to users of an LBS? Are there methods for portrayal that users prefer?"

Chapter 6 described the issues and solutions for modelling information and location in the context of the flora and fauna service.

Re-using Existing Datasets

With respect to data handling, the main challenge was in re-using existing spatial and aspatial data holdings that had been gathered previously for other purposes, such as for scientific research or to provide general information for visitors. These data were largely not in a state in which they could be made available to users of the service owing to mismatches in aspects such as their ontological definition and, their temporal and spatial granularity (Dias et al., 2004b).

The framework defined by Raper et al. (2002) was found to provide a useful way of evaluating these resources and for identifying aspects of the data that needed to be modified to better suit the purposes of WebPark. The main advantage of this framework was in its comprehensiveness, considering both the more pragmatic issues of how data is structured, as well as the issues related to its utility (e.g. relevance and ability to be explored). These latter communicative issues are essential to enable LBS to be dynamic and responsive to the user. In consequence, they are where the perspectives of place and region are found to be most influential since they allow different representations and media to be joined together in the presentation of information.

The main disadvantage of the framework by Raper et al. (2002) is that it is really aimed at pure evaluation of data rather than to guide how it can be transformed to improve its potential for re-use. Filling in how this task could be performed therefore became a main focus of the work.

The process to achieve this was to first separate out data according to whether it was required to be dynamic and interactive (e.g. searchable by location) or whether it was to be used to provide orientation in ways that were relatively static. These two types of data were termed *foreground* and *background* information. The analysis performed previously was used to inform how these two types of information should be structured within a single abstract model, and how a taxonomy based on the foreground features of interest should be defined to instantiate this. This then provided a basis for defining a set of transformation procedures to prepare the data for use in the service. These were illustrated in Figure 6.2.

Geo-enabling

One task that was strongly influenced by the consideration of geographic perspectives was the modelling of locations to 'geo-enable' non-geographically referenced information such as general descriptions of plants and animals, so that these could be searched for spatially.

The use of a regional perspective to model locations was justified here because of the formulation of questions such as "What x can be found at y?" and "Are there x in y", which emphasised this way of thinking. Different ways of modelling regions were considered according to whether a region shared its definition with the semantics of:

- The user and their activities and behaviour,
- the features of interest and aspects related to them, or
- independent of either of these (e.g. based on landscape morphology)

A typology illustrating this classification was presented in Figure 6.11. To some degree, regions could also be unioned to consider semantics from several perspectives, for instance a habitat model for songbirds could be limited by a region describing the area over which a visitor could see songbirds from a trail.

The regions so defined were then used as a way to index information that could be then related to the user's absolute position obtained from the GPS receiver.

Issues and Solutions for Location Modelling

A number of issues came out of following this approach. The heterogeneity of the myriad datasets meant that many different types of region were required, resulting in a fairly large spatial index. This could be difficult to manage and utilise because of the limitations of the mobile client device, such as memory and processor power. Two methods were employed to help overcome this.

The first was to employ independent regions where possible since these could be made to index a wider variety of feature types. This technique worked well if there were discriminants that were sufficiently identifiable and influential in the landscape. For example the catchment morphology was useful because it was readily identifiable in a mountainous environment, had a strong influence on the distributions of many species and had qualities that related to what was visible to a visitor at any particular moment. Thus, though independent it also shared many commonalities with the features they indexed. However, in landscapes that are less well differentiated defining suitable independent regions is much more difficult. The other study area of Texel considered in WebPark is quite flat; so instead land cover types were used. These were less well suited to describing the distributions of wildlife such as birds.

The second approach to managing the index was to follow the *satisficing* principle of Hill (2000) and define regions at the minimum resolution required to satisfy needs. Here, the approach of Jones et al. (2001) was followed of using the bounding boxes of regions instead of their full geometric definition. This worked when the regions were small and compact and so the amount of change in the shape of the region was not so significant. However when the regions were large or more convex the distortions introduced were less acceptable.

Presenting Location for Search

A further problem was how to describe a locational index based on regions to the user in simple terms. Whilst the regions are defined in different ways it could become confusing if these were explained in the interface each time. For example with search options like "... within this valley", "... in this catchment", "... living around me", "... visible from here" etc.

Instead it was felt more useful to not explicitly detail how the location was being determined and favour simpler descriptions such as "... around me" and "... within the whole park". This method makes the presentation of choices for searching more concise though to an extent detracts from the ways visitors actually ask questions, as was described in Chapter 4. Figure 10.2 illustrates how relevant visitors felt the different methods were to searching for information based on the results of the testing.

It is interesting, though perhaps not surprising, to note that people felt the ability to search for general information across the whole park was much less relevant than being able to find information that was related to their location and the space of their activities. A question was also asked about how interested people would have been in the option to search for information using terms that were closer to their experiences and activities. Figure 10.3 illustrates the results.

It is notable that for the most part visitors would have found a greater flexibility in how the search functionality was presented beneficial, particularly in terms of how they see the world. One the one hand, this justifies the use of a region based approach

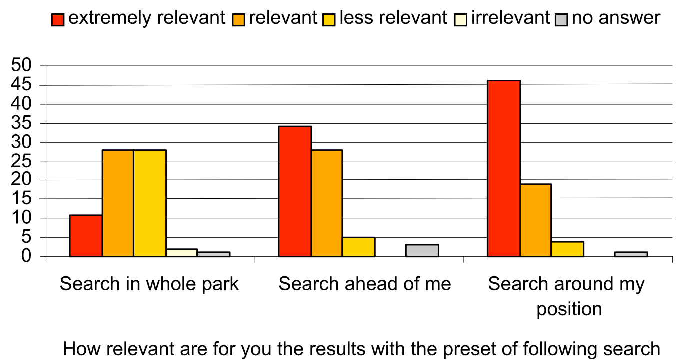


Figure 10.2: Results of user testing on relevance of different types of location based searching. Figure reproduced from Krug and Abderhalden (2005).

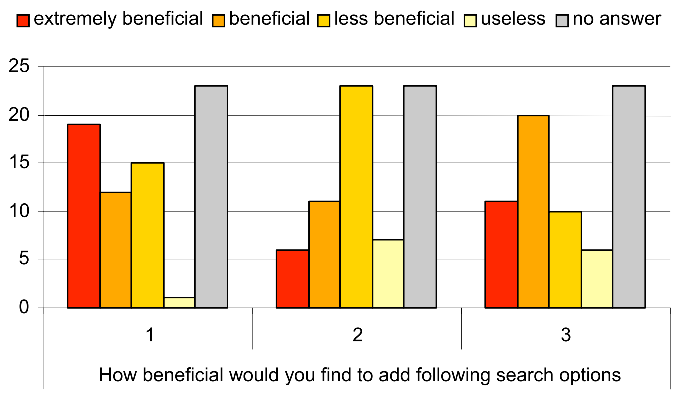


Figure 10.3: Results of user testing on the perceived benefit of additional options for location based searching. Options: 1) Only results that are visible from visitor's current location. 2) Only results that are close to the visitor's location but not necessarily visible from there. 3) Results are related to the time taken to walk to them. The question was not answered by 23 people because it was added at a later stage of the testing. Figure reproduced from Krug and Abderhalden (2005).

to modelling locations since it can offer more flexibility in scoping information than approaches that are more strongly geometric. On the other, it suggests that location regions could be exploited further in how they are presented in the search interface.

Presenting Activities

The issue of how to assist visitors in creating places *ad hoc* was pursued by considering how activities could be supported and these related to locations. The main user activity considered was identifying and finding out what species were likely to be seen around the user's location. The canonical questions "What x is this?" and "Is this an x?" are representative of these, as are the questions "What x can be found at y?" and "Are there x in y?" when the locational reference (y) was the immediate surroundings. Supporting these actions meant that how the species were presented to the users was an important consideration. This was tackled in the construction of species taxonomies and how descriptive information and spatial information was interlinked to these.

Defining a suitable taxonomic ontology is possibly the most difficult task here since it strongly depends on the needs of the action. For instance, if a visitor wishes to identify a bird they may only know what it looks like. So, presenting information about birds in terms of how they are classified in families may be of little use. Few people, for example, can readily distinguish between a falcon and a hawk on first sight. On the other hand, if a person has an idea about what a bird is or wants to know specifically about a certain species of bird, such a classification may be entirely appropriate. At issue then is the way in which perception can influence the creation of places in the identification of a species. Ideally, how the species are presented should relate strongly to how it is experienced.

In this work taxonomies were employed as a form of styling for kinds, that should be defined independently on top of primitive feature categories. Thus, the mechanism for associating taxonomic trees to features was loosely coupled. This echoes approaches used to produce subsumption hierarchies in the development of ontologies by defining a skeleton of self-standing primitive concepts and based on these defining derived concepts more dynamically using a reasoner (Rector, 2003; Dutton and Edwardes, 2006). As such, this approach might offer more flexibility in future developments, not least because semantic classifications would not be limited to tree hierarchies but allow networks of relations to be defined through multiple inheritance. Visual taxonomies were also experimented with, see Figure 6.17, but ultimately only a textual and more family based taxonomy was used. This meant that the service was not as easy to use as it could have been, which is perhaps reflected in the results described earlier in Figure 10.1. In subsequent revisions to the service by the company that has commercialised it (Camineo, 2006) this state has been improved by also supporting visual taxonomies based on colour and pattern for plants and butterflies. However, it is still not a simple problem to solve particularly if a broader range of perceptions e.g. searching by sounds, were to be also employed.

Presenting Spatial Information

There were also occasions when the visitor was more concerned with identifying places to conduct their activities rather than creating them *ad hoc*. This was particularly evident in the question "Where can x be found?". This question was dealt through a spatial perspective either by displaying areal distributions related to a species or individual points of interest. For the most part issues related to this latter type of representation will be discussed in the next section (Section 10.3).

Spatial distributions were attached to kinds of species as a form of descriptive multimedia. Different methods of portrayal were employed including regions (choropleth maps), density surfaces, point distributions of recent observations and point clouds showing distributions of animals from seasonal inventories. Figure 10.4 illustrates how useful visitors found the maps. The results found that the vast majority

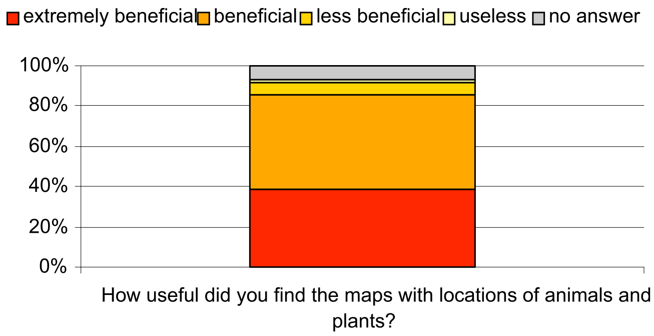


Figure 10.4: Results of user testing on the usefulness of maps showing locations of plants and animals. Figure reproduced from Krug and Abderhalden (2005).

of users thought the maps were beneficial or extremely beneficial. In general maps with symbols were preferred (i.e. those showing recent point observations), though a large proportion of those asked had no particular preference. The least favoured maps were the point clouds (Krug and Abderhalden, 2005, p.17).

In spite of these favourable results, there was an issue in the choropleth representations that aggregated animal counts to units such as vegetation, see Figure 6.21. In particular, wildlife experts at the SNP felt that these misrepresented the true patterns of ungulate distributions in the park. This underlines the problem of using regions to represent a spatial perspective where there are inconsistencies between the semantics being shared.

10.3 Dynamic Views

The final set of research questions aimed to consider the use of dynamic methods for portrayal to enhance how geography was presented visually. These were stated:

- "In what ways are maps and map interfaces for location based services distinct from those of more conventional forms of mapping such as paper and web maps and how can these considerations be implemented in dynamic solutions?"
  - "Can a transformational approach to map adaption be employed to manage such properties?"
  - "What are the situational aspects of location and graphical constraints that need to be mediated for in such solutions?"

These questions were dealt with in Chapters 8 and 9 which describe how map interfaces can be furnished with abilities to transform dynamically added data in ways that consider issues related to abstraction and graphical presentation. These aims were defined within the domain of *portrayal* which seeks to exploit different aspects of a map (Berendt et al., 1998) to bring it closer to the thinking employed by a map user in particular situations. The situation considered here was in the user trying to find out about places that are of interest to them and to relate these places to their changing situation.

Portrayal and Geographic Abstraction

The issue of abstraction is the most important in discriminating portrayal in LBS from presentation with more conventional map media. The aim of portrayal in LBS is to involve how the user abstracts geography in relation to their context and the execution of their activities. This means that the portrayal of geographic information must be flexible enough to accommodate changes in the content depicted and how it is presented in a mobile scenario. In more conventional cartography, at least of topographic maps, the emphasis is instead on the abstraction of descriptions of geographic phenomena and their spatial arrangements. Changes to the content are usually limited, for example to turning on and off predefined layers, because the purpose of the map to describe the locations and patterns of geographic features doesn't really change.

There are of course many examples of maps that step outside such conventions, an obvious example might be web maps providing routes between start and end points defined by a user. For such presentations the same sorts of portrayal issues that have been encountered here are likely to be equally relevant. For instance, in the case of a route map alternative forms of portrayal emphasising how the driver abstracts geography during the course of driving might be more appropriate, as shown in the LineDrive maps of Agrawala and Stolte (2001).

Techniques for Dynamic Portrayal

There are a broad range of techniques that can be subsumed under the term portrayal as used here. However, a trade-off also needs to be made between the specificity of the technique to a particular abstraction and the ability for the method to be generic enough that it can be extended and used for several purposes.

For example, techniques that focus on the map user's location such as variable scale maps and chronographs are useful to answer "Where's my nearest…?" type questions, but their emphasis on a single focus restricts the use of the map much beyond this, for instance to consider places that will be encountered at a future point along a path. The vertical profile visualisation for hikers (Mountain, 2003b) shown in Figure 3.6 is another example. Such a view is limited in what it can show and how it can be extended because of its emphasis on one aspect, the changing height along a path. In this case the limitations of this point of view are outweighed by the usefulness of the presentation method for such a dominant activity. However, in a suite of location-based services the use of many different forms of portrayal would quickly become confusing for the user. On the other hand, more conventional descriptive cartographic presentations have an advantage that they are more generic, supporting a range of different uses and content, but they suffer from the issue of a universal viewpoint that removes the user entirely from the presentation, as was discussed in Section 2.2.3.

In this research, a compromise was sought that would on the one hand consider the specific contextual requirements of the LBS map user whilst on the other being sufficiently generic that it could be employed in a range of situations and for a range of different types of data.

Constraints for Portrayal Solutions

The approach proposed sought to achieve this balance by mixing the need to allow the user to interact with and dynamically modify the contents of the map, with cartographic considerations for effective and faithful presentation.

In terms of the user, the important factors considered were maintaining the situational reference between their position and the information being shown, allowing them to add and remove information important to their activities at will and preserving the ability to interact with symbols to obtain more detailed information.

From a cartographic perspective the aims were to minimise the amount of overlap between symbols, to preserve locally the spatial arrangements of features being shown and to preserve the spatial and topological relationships between the foreground features and background ones structuring the map space. These cartographic considerations are of course also important factors for the user and thus can not be viewed as completely distinct. For example, preserving topological and spatial relations means that users are better able to orientate themselves within the information that is displayed. Minimising overlap helps ensure symbols can be interacted with.

Transformational Techniques

The methods to mediate amongst these considerations were based on transformational approaches for reorganising the foreground features of the map. Within GIScience such approaches can be traced back to the work of Tobler on cartograms (for example Tobler, 1973, 1986). They also share much in common with more recent techniques for variable-scale and non-linear transforms (Harrie et al., 2002; Keahey, 1999) as well as surface parameterisation in computer graphics (Floater and Hormann, 2005). From the non-linear transformation techniques, the idea of separating out magnification and transformation functions was adopted. From surface parameterisation, methods to constrain the transformation function so that it would balance the amount of magnification (which causes the features to be separated) with the management of spatial relationships were introduced.

Technical Innovations

Whilst drawing on such techniques from previous research the application developed here was also quite distinct.

Foremost was the idea of using a transformation approach to reorganise cartographic features. This is not one that has been previously attempted, though as was described in Section 8.2 many techniques for displacement in map generalisation can be conceived in such a manner.

The concept of enhancing the role of the map view in LBS as an interface with independent intelligence to allow it to dynamically adjust the presentation of information has also been suggested by other researchers, for example the *adaptors* of Reichenbacher (2004) though not often implemented. The novelty here was both in its demonstration and in the method of separating volatile foreground features (e.g. points of interest) that induce operations and static background features that provide structural constraints to this process.

The use of a grid based data structure to represent the background features through a shared topology is also not a technique that has been previously shown using geographic data or for constraining variable-scale transformations.

To some extent the ways in which the various transformation methods presented were employed and further developed is also innovative, especially in how they were parameterised as planar variable scale transformations and implemented using a constrained quadrilateral data structure.

The Laplacian method described in Section 9.6.2 was developed largely independently and has not been employed previously in the literature for this setting. Though arguably it is quite similar to approaches described in other fields (e.g. Taubin, 2002).

Evaluation of Solutions

Chapter 9 evaluated the effectiveness of different transformational approaches in achieving map solutions that satisfied the conditions previously outlined. Three methods were evaluated, two based on a grid (termed the KT-grid and the functional grid) and one a triangulation, using a set of qualitative and quantitative measures.

The techniques based on a grid were found to be best at ensuring the reference between the user's absolute position and map data being shown could be maintained. This was because the grids provided a more straight-forward method to map between the position return by a GPS and the (deformed) coordinate space of the map. The functional grid and the triangulation methods were best able to allow the background features to influence the presentation, since these could be represented explicitly within the transformation process. These two approaches also maintained the spatial relationships of the transformed features better, in terms of the local preservation of angles. The triangulation approach was best in achieving a separation amongst the features, which is important to ensure they can be interacted with.

Suitability of Techniques for LBS

In general, all the methods were able to meet the conditions required of them to some extent. The suitability of each really depends on which constraints are felt to be most important by an application designer.

If the separation is the most important factor then the triangulation offers the best approach since it models the distance between features explicitly. If speed is the greatest concern then the KT-grid offers the best approach since as well as producing a solution in the shortest time, it can be parameterised quickly and implemented using fairly low level data structures. In spite of this, the approach was not sufficiently fast to compute a solution when tested on the current generation of mobile device technologies. Indeed a general criticism of all these approaches is that they overlooked the factors of speed and optimisation and so have not been properly tested in a mobile setting. The reason for this is because it was discovered early on in the work that focusing on such issues would limit the scope of research to consider restrictions (e.g. processing power and available memory) that are highly transient. Instead the route taken was to focus on more more basic research issues which are less likely to disappear any time in the near future. However, the Laplacian method that was developed but not fully evaluated would appear to have a greater potential to offer sufficiently good and fast solutions that it might be best suited to contemporary devices.

Integrating Semantics

The transformation frameworks described are capable of supporting a range of different data types (points, lines, polylines) and their symbolisation as background and foreground features. However, the issue of how to select which are the most important background features that structure a situation has been largely neglected. This will need the semantics of features to be much better related to the needs of the LBS user. On the one hand, the approaches employed here can be seen as a step toward better achieving this since they allow the more geometric issues associated with the presentation to be separated out. Hence, semantics can be dealt with more in isolation, for example using ontologies (Dutton and Edwardes, 2006; Kulik et al., 2005), and then synthesised into the solution through structural constraints and parameterisation. On the other hand, it can also be argued that the solutions are too spatial and thus, beyond maintaining the positional reference, miss out on a proper consideration of how situation and location structure space in the description of places. In addition, how other portrayal operations might be integrated within the framework has not yet been properly considered, for instance the portrayal of linear networks as schematised foreground features (Avelar, 2002; Cabello et al., 2005), and the reduction in the volume of foreground points (Burghardt et al., 2004; de Berg et al., 2004).

Chapter 11

Conclusion

11.1 Achievements

This thesis has offered several significant research contributions.

Re-placing Geography in LBS

The research was approached by considering the issue of how geography must be considered and re-introduced into location based services. This approach differs from most others which have often tended to focus either on more technical issues related to the integration of technologies, side lining geographic considerations into more simplistic systems of spatial representation, or emphasise particular aspects within an LBS in isolation, such as activity, maps, or location modelling, when these can be better dealt through the more holistic view points that geography offers.

The emphasis here was on identifying and implementing such a consolidated approach employing different geographical perspectives as a unifying framework. In following these aims the research was fortunate to be undertaken within the context of a wider project (WebPark). In particular this allowed some escape from technical issues that can otherwise swamp research in this domain.

Geographic Perspectives in Natural Environments

Part of the reason why it was necessary to follow such an approach was because of the setting the service was deployed in, natural and protected areas. This also distinguished this work from much of the other research which is based on the urban environment, on road networks or inside buildings. There are specific considerations that relate to this type of environment.

Natural Borders

One factor is that rural environments on the one hand lack many topographic features that strongly delimit and structure other types of spaces, e.g. roads and settlements. On the other hand, they contain many overlapping natural borders, for example due to the landscape morphology, that strongly influence the perception of space and how activities are performed. One effect of this was that the research needed to adopt novel approaches to defining how locations were modelled and how these could structure information furnished by the service.

Wildlife Activities

A further complexity related to this setting was that the types of things that interested users were often not static and easily localisable, for example wildlife. This contrasts with more anthropogenic environments where much of the volatile information can be represented as stable points of interest. This forced a focus in the research to consider the issue of how people 'create places' through there activities and ways to support this action through how information was presented.

The results of user testing, described in Chapter 10, affirm that visitors found the service beneficial justifying these as achievements. In addition the service continues to be used as part of a successful commercial product (Camineo, 2006), albeit with revisions and improvements by the company.

The Transformational Approach for Portrayal

A second set of achievements relate to the design and demonstration of techniques for dynamic map portrayal in location based services. This part of the work was focused on much more fundamental research issues, related to how the properties of a map space can be identified and exploited to perform portrayal operations.

Intrinsic Properties of Surfaces

Applying intrinsic surface characteristics has received little attention in GIScience outside work on cartograms and hence the techniques not only help to expand this research frontier but also bring in new insights from outside the domain, for example from computer graphics. These should be interesting to a range of research in GIScience sub-disciplines such as automated map generalisation and geovisualisation.

Interface Design for Map Views

The research also breaks new ground in efforts to design interfaces for portraying geographic information that operate independently in making decisions on how information can be best presented based on different cartographic and contextual considerations. Such desires have been suggested in previous research but demonstrations are often missing.

In particular, the technique to separate out different types of information (foreground and background) and represent these using different but integrated data structures (e.g the feature aligned grid) should provide useful results to other researchers in the field of portrayal.

11.2 Insights

How Geography Shapes LBS

The foremost insight that has been gained through this work has been the critical need to involve geography in LBS research and the difficulty of achieving this. This need is prompted by the desire for location based services to mediate in and exist adjoint to people's basic and everyday experiences of the world when these are shaped by different ways of thinking that are essentially geographic. Whilst such perspectives have informed how geographic information is represented, this often leads to an overemphasis on a spatial underpinning and on a scale dependent simplification of these concepts which can alienate the user from the geography being presented.

Place as Framework for LBS Design

In particular, the perspective of place would appear to have much to offer LBS research because it is able unify different aspects such as perception, activity and situation which are often otherwise dealt with separately. The issue with place is that for most part it is a perspective that is non-representational, emerging through processes of experience within otherwise undifferentiated space. LBS researchers need to support such a perspective by developing technologies that might be seen more as frameworks to stimulate the user's imagination, exploration and interaction, "imaginative spaces", than as appliances for dispensing information. In achieving this how information is presented is of utmost importance. This is not meant to imply a move towards complex systems for augmented reality, but rather a change in the dynamic between the user as a consumer of information and designer as its author, into one in which the user is very much also the author of their experience and the designer acts to provide a framework to best enhance that. This view is emphasised in the idea of "creating place".

Regions for Organising Geographic Information

The perspective of region also suffers from being difficult to represent but can offer much to supporting how information is organised and structured in ways that are closer to peoples' cognition. This perspective has received more attention in GIScience, particularly in work on qualitative spatial relations, spatial cognition and language. Its continued emergence as an important perspective for research is also clearly evident in the developing fields of geographic information retrieval and geo-ontologies. The insights here relate to the use of the regional perspective as a way to model location so that it is more sensitive to both the geography of the environment the service is used in and the characteristics of the information that the locations will be used to contextualise.

Deforming Space in Portrayal

The perspective of space is of course the most well developed in GIScience. The insight here was on how this perspective can be managed when it is used to present information and represent the other ways of thinking. One aspect to this was how the intrinsic properties of represented space can be exploited better to consider a range of constraints that depend on both the needs of the perspective being described (e.g. the situational context and interests of the mobile user) and the effective graphical presentation of the information.

11.3 Limitations

Evaluation

Probably the greatest limitation of this work has been in the evaluation. Whilst the results of the continuous and final user testing provided some insight into the success of the approaches employed this was limited and not sufficiently focused on many of the concerns outlined in this work. The reasons for this were that the testing needed to encompass a broad range of issues related both to each of the services and to the technical capabilities of the system overall. This meant the scope of questions concerning particular aspects of the services was reduced.

The issue of evaluation of such techniques for portrayal, visualisation and service design is also a general problem in GIScience research. Few methodologies are available that can encompass the aspects that centre GIScience research. Those that are available tend to focus on specific concerns, such as usability, using methodologies that have been developed outside the field and so which may rely on models that are not geographically founded.

Reliance on Geometry

It might also be argued that the methods developed in the research suffered from some of the very issues that it aimed to avoid. In particular, parts can be seen as over-reliant on geometric representations of spatial data, such as encoding of locations which might be seen as too static and without sufficient considering of aspects such as people's behaviour in space and time.

To a degree these latter concerns were dealt with in parallel to this work by other members of the WebPark consortium (Mountain, 2006; Dias and Edwardes, 2006) and can be seen as complimentary. However, more generally the work needed to find a compromise that allowed a level of objectivity that spatial representations can provide while still considering the more subjective aspects involved in people's encounters with space. Achieving a satisfactory balance to this problem will require further research. However, the techniques proposed here can at least be seen as a step towards this goal and as providing a framework that will allow more semantic and contextual considerations to be better integrated.

11.4 Open Problems

A number of open problems were suggested by this work. These can be stated:

- How can methodologies for evaluating portrayal and design in location based services be developed that encompass underlying models of geographic perception and cognition?

- How can contextual aspects and semantics be better integrated in portrayal techniques, and how can different techniques be better integrated together within dynamic map interfaces (e.g. schematisation and level of detail operations)?

- How can the creation of place be better supported through the presentation of information spaces and a consideration of the perceptual aspects of environmental experience?

Evaluation Methodologies

The first question arises directly out of the limitation described in the previous section and can be seen as a concern that will continue to influence all further research. Location-based services are a subject of research for myriad different academic disciplines, such as informatics, locative media and human computer interaction, each of which can influence its development. Here the claim of geography within LBS has been staked, however continued research from this perspective will be hampered without better systems of evaluation that are based on geographic models. These will need to take a holistic approach to analysis that not only considers the utility of geographic representations but also the success of systems in informing peoples' geographic perception in undertaking the activities that interest them.

Semantics in Portrayal

The second open problem considers how portrayal techniques can be further developed and integrated to better present aspects of geographic features differently in varied roles and situations. This work focused on developing a fairly generic framework for re-organising map features according to different contextual and graphical considerations. Other approaches in portrayal, such as schematisation and adaptation, have likewise focused on relatively universal application. One the one hand, this provides a geometric basis into which semantically related concerns can be embedded without making prior assumptions about these implicit in the design. On the other hand, there needs to be further work on how to model the semantics of situational constraints and how best to link them with such frameworks.

Representing the Non-representational

The final question relates to the inclusion of non-representational aspects of place in LBS. An issue that was identified in this work was the need to present information related to activities in ways that appeal to the perception and situated experience. This problem needs to be explored further if LBS are to intervene more intimately in people's geographic awareness. One possible route in exploring this issue is through ontologies (e.g. as visual taxonomies) that can be dynamically employed to allow varied types of views according to the needs of different actions and situations.

11.5 Outlook

The work expounded here will continue to be developed, in particular in the directions outlined in the previous section. In addition, a number of avenues will be explored that exploit the techniques developed here more directly.

Extending the Transformational Approach

One endeavour is to investigate whether the transformational approaches can be extended to other portrayal operations and feature types, some ways in which this could be achieved were suggested in Section 9.6. In pursuing this goal more detailed models of semantics with which to parameterise the frameworks and influence the transformations will need to be defined.

Extending the Application of Regions

It is also aimed to develop the modelling of regions within the wider application field of geographic information retrieval, both in natural and anthropogenic settings. To achieve this a more comprehensive model of how people see geography affording actions and activities in different types of situations will need to be developed. In addition, how geographic instances in these models can be linked together, perhaps as networks or hierarchies, and how flexible these structures need to be to support different activities will be explored.

Identifying Place from Spatio-temporal Behaviour

A continuation of this research will also be to analyse and develop methods for analysis and evaluation that are based on the spatio-temporal behaviour of LBS users. The aim will be to try to better understand how and where people create places and the degree to which this is a subjective process or one that is influenced by situational factors such as topography. In relation to this, it is aimed to consider how different ways of presenting place might influence people's behaviour and encourage their involvement within natural settings.

Appendix A

Categorised list of questions

Table A.1: questions categorised

question	action	subject	object	action category	act	geography
The marmots don't have any other predators than the golden eagle do they?	being predated on	marmots	golden eagles, other predators	animal relation	inform	non-spatial
Have the marmots already started hibernation?	starting	marmots	hibernation	life-cycle	inform	temporal
What species is this frog?	being a kind of	this frog	what species	class/object name	identify	place
Is the fish stock sustained artificially?	being sustained artificially	fish stock	(SNP)	management	inform	region
Is this caused by browsing?	being caused	this (leaves)	(something) browsing	causation	verify	place
What droppings are these?	being a kind	these (droppings)	what droppings	class/object name	identify	place
What is this? (droppings)	being something	this (droppings)	what	class/object name	identify	place
What kind of tracks are these?	being a kind	these (tracks)	kind of track	class/object name	identify	place
What kind of tracks are these; in which direction did the animal move?	being a kind	these (tracks)	kind of track	class/object name	identify	place
There are two alpine choughes, are they a pair?	being, being a couple, breeding	two alpine choughes	a couple	animal relation	inform	place

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Table A.1 – continued from previous page

question	action	subject	object	action category	act	geography
That was a jay wasn't it?	being called	this (bird)	a jay	class/object name	verify	place
Is this a true ant-hill?	being something	this (mound)	true ant-hill	class/object name	verify	place
Was this a woodpecker's work?	being caused by	this (hold)	a woodpeckers work	causation	verify	place
Which bird is singing there?	singing	(the bird) there	which bird	behaviour	identify	place
Can animals be watched depending on the time of day?	watching	animals	time of day	visitor activity	observe	temporal
Is this dropping from a red deer?	produced by	this dropping	a red deer	behaviour	verify	place
This is unusual isn't it, a lone red deer doe?	being alone	a female red deer	something unusual	behaviour	inform	place
Does the eagle also hunt birds?	hunting	eagle	birds	animal relation	inform	non-spatial
Do the red deer have a certain daytime activity?	behaving, acting	red deer	daytime activity	life-cycle	inform	temporal
This whistle is made by the marmots, isn't it?	making a noise	this whistle	marmots	behaviour	verify	place
Are there problems with bark beetles in the SNP?	having problems	bark beetles	SNP	management	inform	region
Was this a bird (nutcracker sound)?	making a noise	this sound	bird	behaviour	identify	place

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Table A.1 – continued from previous page

question	action	subject	object	action category	act	geography
What kind of droppings are these? Why does they contain so much hair?	being a kind of	these (droppings)	what kind of dropping	class/object name	identify	place
Which woodpecker made the hole in the larch over there?	being caused by	this hole in the larch over there	which woodpecker	causation	verify	place
Will a golden eagle also fetch such big marmots?	fetch (hunt)	golden eagle	big marmots	animal relation	inform	place
How are the bearded vultures fed?	feeding	bearded vultures	how	animal relation	inform	non-spatial
(bearded vulture observation) is this a wild bearded vulture?	being called	this (bearded vulture)	bearded vulture	class/object name	verify	place
When did the releasing start? (bearded vultures)	releasing	bearded vultures	when	life-cycle	inform	temporal
What is this white foam on the flower there? (made by a cicada species)	being caused	this white foam on the flower	what	causation	identify	place
Are there also bears in the SNP?	living	bears	SNP	existence	inform	region
Is the animal stock in SNP documented?	being documented	animal stock	SNP	management	inform	region
Are these all marmot holes?	being something	these (burrows)	marmot holes	class/object name	verify	place
How many animals are radio-tracked in the SNP at the moment?	being radio-tracked	animals	SNP	management	inform	region

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Table A.1 – continued from previous page

question	action	subject	object	action category	act	geography
Are the bearded vultures radio tracked as well?	being radio-tracked	bearded vultures	(SNP)	management	inform	region
Does rabies occur in the SNP?	rabies	occurs	SNP	management	inform	region
What kind of natural predators do they have? (marmots)	being predated on	marmots	enemies (predators)	animal relation	inform	non-spatial
The little trees are all pine, aren't they?	being called	the little trees	pine	class/object name	verify	place
What tree species is this?	being a kind of	this (tree)	what tree species	class/object name	identify	place
Is this the procumbent form of the mountain pine?	being a kind	this (tree)	procumbent for of the mountain pine	class/object name	verify	place
These pines are healthy aren't they?	being healthy	these pines	healthy examples	life-cycle	inform	place
Why have these trees died?	dying	these trees	why	life-cycle	situate	place
Why is this tree twisted?	being twisted	this tree	twisted why	properties	identify	place
Are other important grass species as well?	being important	grass species	something important , SNP (implied)	qualities	inform	region
Is this an alpine rose or a rhododendron?	being called	this (flower)	alpine rose or rhododendron	class/object name	verify	place
What lichen is this? is it evergreen?	being a kind	this (lichen)	what lichen	class/object name	identify	place

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Table A.1 – continued from previous page

question	action	subject	object	action category	act	geography
What species of flower is this ?	being called	this (flower)	what species	class/object name	identify	place
How old are these trees?	ageing	these trees	how old	life-cycle	inform	place
Will these dead trees be removed some day?	being removed	these dead trees	some day	management	inform	place
Are these lichens also epiphytes?	being a kind	these lichens	epiphytes	class/object name	inform	place
Are these trees called 'Legföhren'?	being called	these trees	legfohren	class/object name	verify	place
How long does the decomposition of dead trees take?	decomposing	dead trees	how long	life-cycle	inform	temporal
Are all these stumps remnants of the last woodcut?	being remnants	these stumps	remnants of the last woodcut	management	inform	place
Is this also a gentian?	being a kind	this (flower)	a gentian	class/object name	verify	place
Is this flower called 'alpine rose'?	being called	this flower	alpine rose	class/object name	verify	place
Is this monk's hood (aconitum)?	being a kind	this (flower)	monk's hood	class/object name	verify	place
Is this pestwurz (petasites albus)?	being called	this(flower)	pestwurz	class/object name	verify	place
Was this pine killed by the cold?	being killed	this pine	the cold	life-cycle	situate	place
What kind of tree is this?	being a kind	this tree	kind of tree	life-cycle	identify	place

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Table A.1 – continued from previous page

question	action	subject	object	action category	act	geography
The little trees are older than the big ones, aren't they?	being older	little trees	big trees	life-cycle	inform	non-spatial
What kind of trees are these?	being a kind	these (trees)	what kind	life-cycle	identify	place
Which bellflower is the one that's so common here?	being common	bellflower	here (SNP)	qualities	inform	region
Why do so many trees have two or more stems?	having two or more stems	trees	two or more stems	properties	inform	place
What kind of tree is this (arve)?	being a kind	this (tree)	what kind (arve)	class/object name	identify	place
What kind of a flower is this?	being a kind	this (flower)	kind of flower	class/object name	identify	place
Is this edelweiss?	being called	this (flower)	edelweiss	class/object name	verify	place
Why are there only pines here?	occurrence	pines	here	existence	situate	region
How old is this tree? (three times)	age	this tree	how old	life-cycle	inform	place
Is this a mountain pine?	being called	this (tree)	mountain pine	class/object name	verify	place
Where do the animals stay usually?	staying	animals	where	existence	locate	space
Are there any marmots here?	occurring	marmots	here	existence	occur	region
Do ibex occur here?	occurring	ibex	here	existence	occur	region
Are the marmot burrows always exposed south?	being exposed	south	marmot burrows	properties	situate	space
Are there also snakes?	occurring	snakes	there	existence	occur	region

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Table A.1 – continued from previous page

question	action	subject	object	action category	act	geography
Can any other reptiles be found?	finding	reptiles	(SNP)	visitor activity	occur	region
Are there any bark beetles?	occurring	bark beetles	there	existence	occur	region
Do ibex and chamois occur together?	being together	ibex and chamois		animal relation	situate	space
Is it possible to see animals in the Ftur valley?	seeing	animals	Ftur valley	visitor activity	observe	region
Are there roe deer up here?	occurring	roe deer	here	existence	occur	region
What tit species occur here?	occuring	tit species	here	existence	occur	region
Are there fish in this creek?	occurring	this creek	fish	existence	occur	region
Can marmots be found on Stabelchod as well?	finding	marmots	Stabelchod	visitor activity	observe	region
Where do the alpine jackdaws nest?	nesting	jackdaws	where	behaviour	locate	space
Can red deer be found on this side of the valley as well?	finding	red deer	this side of the valley	visitor activity	observe	place
Which further animal species can be observed on this trip?	observing	animals	this trip	visitor activity	observe	place
Isn't it too wet for the ants here?	being too wet	here	ants	qualities	situate	place
Are there only male red deer in Val Trupchun?	living	male red deer	Val Trupchun	existence	locate	region
How big is a marmot population?	extending	marmots	(SNP)	quantities	locate	space

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Table A.1 – continued from previous page

question	action	subject	object	action category	act	geography
Are there mountain pipits in Val Trupchun?	living	mountain pipits	Val Trupchun	existence	locate	region
As there a chance to observe a golden eagle on this trip?	observing	golden eagle	this trip	visitor activity	observe	place
Are there golden eagles and bearded vultures?	occurring	golden eagles, bearded vultures	there	existence	occur	region
Have bears/ wolves/ lynxes been living in this area?	living	bears,wolves, lynx	this area	existence	occur	region
Do the marmots also live in the forest?	living	marmots	forest	existence	locate	region
Where do the birds breed?	breeding	birds	where	animal relation	locate	space
Where were the bearded vultures released?	being released	bearded vultures	where	life-cycle	locate	space
Can frogs be found here?	finding	frogs	here	visitor activity	occur	region
Are there fish in the creeks of the SNP?	living	fish	creeks of the SNP	existence	occur	region
Was this caused by 'Lothar' or by an avalanche?	being caused by	this (clearing)	lothar, avalanche	causation	inform	place
There are some larches here. is that dependent on the soil or on the altitude?	being caused by	some larches here	soil and altitude	causation	situate	place

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Table A.1 – continued from previous page

question	action	subject	object	action category	act	geography
At which altitude is the timber line? will we pass it on our way?	lying, passing	timber line, we	what altitude, our way	quantities	locate	space
Is this caused by fire?	being caused	this (mark)	fire	causation	verify	place
Are the mountain pines on the southerly exposed slopes a different colour?	lying	mountain pines	southerly exposed slopes, colour	quantities	inform	space
What flowers are there still in blossom?	being in blossom	flowers	what, (SNP)	life-cycle	occur	region
Is this grass regularly cut?	being cut regularly	this grass		management	situate	place
Might this be named an upland moor?	naming	this (place)	upland moor	class/object name	situate	place
What are the main tree species of the SNP?	occurring	tree species	SNP	existence	occur	region
Are there also berry-bearing bushes?	occurring	berry-bearing bushes	there	existence	occur	region
Is this a monoculture?	being a kind	this (habitat)	mono-culture	class/object name	situate	place
Up to what height do foliage trees occur here?	occurring	foliage trees	here	existence	locate	space
What's the tree limit in SNP?	lying	tree limit	SNP, what	quantities	locate	space
Can deciduous trees also be found in the SNP?	finding	deciduous trees	SNP	visitor activity	occur	region

continued on next page

Table A.1 – continued from previous page

question	action	subject	object	action category	act	geography
Is there fog here so often that there are so many lichens on the trees?	being caused by	fog	here, lichens	causation	situate	place
Do these lichens occur only here?	occurring	these lichens	here	existence	locate	space
Is this a pasture for cows? (Alp la Schera)	being a pasture	this (meadow)	cows	animal relation	situate	place
Can deciduous trees also be found in the SNP?	finding	deciduous trees	SNP	visitor activity	occur	region

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